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LAKEHURST, NEW JERSEY

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FINAL REPORT

THE CORROSION CONTROL OF
FASTENING SYSTEMS FOR
AIRCRAFT CARRIER STEAM CATAPULTS

NAEC CONTRACT NO. N00156-73-C-0852

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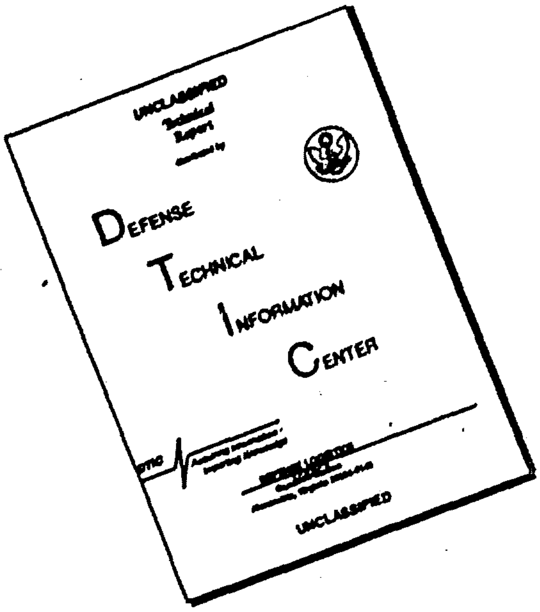

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NAVAL AIR ENGINEERING CENTER

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Various coating systems were evaluated by short term screening tests and long term environmental tests. These coating systems were selected for applicability on threaded fasteners for an aircraft carrier deck environment not exceeding 200°F. Additional coating systems and a corrosion resistant alloy were similarly evaluated for applicability at 700°F for steam pipe flange fasteners.

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The results of the overall program strongly indicate the desirability of thick protective coatings (greater than 0.5 mil), elastic sealants, and corrosion resistant alloys. Additionally, some design changes in existing hardware are recommended in order to minimize corrodent entry and accumulation.

I. INTRODUCTION

A. The steam catapult system is exposed not only to steam and high temperatures, but also to sea water, salty air, jet fuel, hydraulic fluids, detergents, lubricants, solvents, and general neglect during service. General maintenance is scheduled after extended periods of time, so that during a major overhaul (approximately every 4 years) it becomes necessary to replace large numbers of fasteners to restore the system to a "new" condition. The fasteners which clamp the various components together are usually scrapped or burned away because of their deteriorated condition.

B. This program was conceived for the purpose of determining which materials and alloys are necessary to prevent a massive corrosion attack of fasteners and the materials they join. Specifically, the scope is limited to fasteners used for high temperature service up to 700°F as well as those used at temperatures up to 250°F with a broad environmental exposure.

C. The 250°F deck condition is common to a large number of bolts used to fasten the bridle arrester track. These socket head or external wrenching bolts are situated in counterbored holes where liquids are normally entrapped and migrate down to a blind threaded area where severe corrosion is initiated. Removal of the bolt is difficult and sometimes impossible without resorting to drilling. Repair of the hole requires welding, drilling, and tapping.

D. For the 700°F application, uncoated studs and nuts are used to clamp together the steam pipe flanges which are originally painted with an ineffective aluminum silicone coating. The pipe and flanges are covered with insulation which becomes soaked with corrodents from deck leakage. Corrosion attack is so intense, the fasteners seem to become "welded" into the flange and require burning and hammering in order to remove them.

II. SUMMARY

A. PROCEDURES AND RESULTS. After a visit to the U.S.S. Saratoga, the mechanical parameters of this study were explored before initiating screening tests of various coating systems. These tests were conducted with simple fastened systems using a 5% salt spray environment and an oven at 700°F. The best systems observed were tested in nine-month exposures using larger fasteners, more realistic joints and the simulated environmental exposure of an operational aircraft carrier steam catapult.

Although design changes in the basic hardware will prevent corrodents from entering blind holes, the major attack is on exposed surfaces which require much more protection. Corrosion resistant alloys perform well but thick plated coatings also prevent corrosion for extended periods. The use of thick noble coatings on exposed surfaces and sacrificial coatings on unexposed surfaces was found to be successful. A polysulfide sealant employed to prevent corrodent seepage into blind holes was very useful. It was applied over zinc and over cadmium and allowed to cure on the fastener before being torqued in place.

An exposure aboard ship was found to produce the same kind of attack on high temperature fastening systems as found in a long term simulation test. Also, electrochemical tests provided quantitative data which supported the visual evidence accumulated over many months of laboratory tests.

B. CONCLUSIONS.

1. The normally supplied cadmium thickness on alloy steel fasteners for bridle arrester track use is not able to cope with the severe corrosion environment encountered in service. The maximum thickness offered under QQ-P-416C is not thick enough to prevent rusting of the bolt threads. Therefore, a much greater thickness of cadmium should be employed (more than 0.0005").

2. A heavy nickel plating will protect the heads of bridle arrester track bolts but cadmium plating should be employed over it to protect the threaded holes and to lubricate.

3. Sealants provide excellent protection and should be employed whenever possible to prevent the flow of corrodents.

4. Noble coatings and corrosion resistant alloys outperform sacrificial coatings in high temperature applications.

C. RECOMMENDATIONS.

1. Investigate sacrificial coating systems using cadmium or zinc and cadmium with total thicknesses of 1 mil (0.001").

2. Investigate a coating system where nickel protects the exposed surfaces and cadmium over nickel protects the unexposed and mating surfaces.

3. Investigate coating systems where sealants are employed in combination with the above mentioned coatings.

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VII. CORROSION PROGRAM

A. INTRODUCTION.

1. General. Corrosion can never be completely arrested, but merely resisted, since it is theoretically impossible to eliminate it, but it is possible to control it. Even in this ultra-modern age of moon exploration, the "back to nature" process of a metal returning to its most stable chemical form must be tolerated.

The literature is full of corrosion studies of sufficient merit to warrant a life-long dedication to the reading of selected topics. So many investigations into a myriad of problems have already been published that it seems unlikely to have to search deeply to find an answer to a specific problem. But, this is not the case because of the many different parameters affecting each problem.

Naval structures are used in a unique environment consisting largely of salt laden air and very conductive water. Very few land based industries have similar environments and usually do not have time, manpower and material restrictions common to a crowded warship at sea. These are the parameters which directly affect housekeeping or maintenance, and create problems which compound until severe degradation occurs. At this point, better systems are needed which will withstand the test of time.

The steam catapult system is exposed not only to steam and high temperatures, but also to sea water, salt air, jet fuel, hydraulic fluids, lubricants, detergents, solvents, and general neglect during service. While the latter condition is not planned, it often becomes necessary as a function of expediency in conducting missions.

General maintenance is scheduled after extended periods of time, so that a major overhaul becomes necessary to restore the system to a "new" condition. This work is costly and time consuming, especially where large areas have to be refurbished. The fasteners which clamp the various components together are usually scrapped or burned away because of their deteriorated condition.

This program was conceived for the purpose of determining which materials and alloys are necessary to prevent massive corrosion attack of fasteners and the materials they join. Specifically, the scope is limited to fasteners used for high temperature service up to 700°F and for those used up to about 250°F but exposed to a wider variety of conditions.

The latter, or deck condition, is common to a large number of bolts used to fasten the bridle arrester track. These socket head or external wrenching bolts sit in a counterbored hole in manganese bronze, stainless steel or alloy steel, where liquids are normally entrapped. The liquid migrates down to the blind threaded area imbedded in alloy steel and causes corrosion severe enough to prevent removal of the bolt by conventional torquing. The bolt sometimes breaks or the drive is reamed out. Welding a nut on the head sometimes facilitates removal but oftentimes a torch is required to burn the "remnants" out. When the threaded hole is destroyed, a larger hole is drilled, tapped and an insert installed, or if the hole is too large, it is filled with weld metal, redrilled, and tapped.

The corrosion is due to the presence of sea water, splashed around the deck for various purposes including fire fighting. Other liquids such as AFFF (fire fighting foam), jet foam, detergents, hydraulic fluids, paint strippers, and perhaps even fresh water may find their way into the crevices and recesses between mating structural surfaces as well as those provided by the threaded fasteners. It has been firmly established that voluminous corrosion products between structural mating surfaces can produce sufficient force to exceed the maximum tensile strength limits of fasteners used to provide clamping. Even though sacrificial coatings are usually employed on bolts and nuts to resist corrosion, they can provide only a finite amount of service before they are consumed or depleted. Of course, some coatings are better than others. Traditionally, electroplated cadmium has exhibited the most protective properties in marine environments. It is very widely used by most industries for other applications too.

In this particular application, cadmium has been used in a thickness of 0.0002" to 0.0004". Typically, the actual thickness is likely to be closer to the minimum value. When this factor was considered recently, a recommendation was made by SPS to increase the thickness to a minimum of 0.0005". While this improvement should provide more lasting protection to the joint because more sacrificial metal is present, it may not prevent the aforementioned problems from reoccurring. The reason for this is because of the joint design which invited corrodents to penetrate by gravity or capillary action.

The solution to this particular problem is typical of the solution to every other bolt problem in the steam catapult area. Since the corrosion intensity is on a massive scale, protection should be proportional to it. Unfortunately for threaded fasteners, the fit is critical to maintain clamping load, and insufficient allowance for appreciable coating thickness is the usual practice. The fastener material, however, is a contributory factor and should be considered along with the mechanical and environmental parameters. Of primary concern is the propensity for the bolt alloy to corrode when barrier or sacrificial coatings are depleted or destroyed.

Below deck, temperatures of the steam catapult hardware reach as high as 700°F and, combined with the leakage of contaminant liquids from above, cause extensive corrosion of fittings and fasteners. Lagging material, made of magnesium silicate or equivalent compounds, seems to act as a wick for maintaining moisture laden concentrated salts adjacent to the hardware. Temperature cycling, humidity and leakage contribute synergistically to provide a haven for corrosion to occur. Conventional coatings such as cadmium or zinc cannot be used because they may cause stress alloy cracking at this temperature. Corrosion is so intense that it is impossible to remove the nuts. They are burned off and the fastening system is discarded.

In order to prevent the overall problem, temperature resistant coatings must be employed over the bare metal fittings in thicknesses sufficient to thwart the penetration of corrodents. These thicknesses are usually recommended in mils, whereas fastener coatings are specified in fractions of one mil. Therefore, if it is possible to provide adequate protection to these fasteners, the protection must emanate from quality rather then quantity. Sacrificial coatings have a history of not lasting long enough,

although much of the reason is due to minimal thickness requirements. On the other hand, if an excess of a sacrificial coating were present, its surface would be largely an accumulation of corrosion products, generated over a period of time. It is reasonable to assume that an adequate thickness of a more noble coating on the fasteners would be a better approach in combination with a thick barrier coating on the pipe flange. Another alternative is a high temperature alloy which does not produce voluminous scale in this environment.

Whatever the solution, it must be weighted in accordance with established procedures, other components in the system, and overall cost. The two areas discussed here represent only a small fraction of the fastener corrosion problems aboard an aircraft carrier, but are indicative of the severity of the attack and of the concern to the Navy. This program was aimed at the solution of general fastener corrosion problems. By utilizing "state of the art" coating technology to determine if coatings are capable of adequate protection in thicknesses which do not cripple the performance of threaded fasteners, this goal should be reached. Alternately, more corrosion resistant fasteners, due to better alloys, may also provide a solution.

In order to study the cause and effect relationship, a model was produced, where the effect could be duplicated. If one model duplicated the various corrosion conditions found in service, the study would be much easier. This is not the case however, and a number of models or environments had to be used, each for a particular problem. Two specific problems in steam catapult systems were selected from this program. They were chosen because they are representative of the more troublesome problems and are far enough apart environmentally to require different approaches.

2. Carrier Visit. One week after the initiation of this study, the U.S.S. Saratoga (CVA60) was visited at the Norfolk Naval Shipyard by three SPS representatives. At this time (April 12, 1973), the track and launch valves were in an advanced state of disassembly and repair. Several visible areas required a great deal of work.

Bolts installed on the track covers were primarily socket head cap screws or 12-point external wrenching bolts. After exposure, the lobes of the 12-point bolts corrode and crumble away, leaving no wrenching surface. On occasion, the head is mechanically damaged by large metal objects and wrenching becomes impossible.

Resident personnel prefer the socket head to the external wrenching bolts (EWB) but would like to try an EWB with a hex recess instead of a lightening hole. If one of the drives is damaged, the remaining one could still be used.

Below deck in the launch valve room, the situation seemed worse than the description in the previous section. It was learned that a high temperature aluminum silicone paint was used on the steam pipes, but the result was complete flaking of the paint and zero protection.

Conversation with knowledgable military and civilian personnel revealed a situation very difficult to completely remedy, due to the disregard for expending time for repairs at sea. The seamen who maintain the system are under pressure to minimize downtime and perform little or no preventative

maintenance. Therefore, any system installed at dockside gradually deteriorates until the next dockside visit. While on duty station, the carrier is attended by local "craftsmen" who are not responsible for the catapult system, so that the only real attention given is by the home port maintenance teams and by the NAEC engineering department.

Further hardships encountered are limited funds and time for maintenance and repair. This condition generally leads to increased deterioration since marginal materials and solutions are used instead of more permanent remedies.

3. Evaluation of Exposed Bolts. A number of 12-point external wrenching bolts purchased from SPS were installed in the 4340 steel impact bridle arrester track and were exposed to service for a few months. At this time, new bolts manufactured at the same time were substituted in their place and the exposed bolts were examined.

At first glance they looked very rusty, but after cleaning in solvents and with soap and water, the rust blanket was washed away. The cadmium plated alloy steel bolts (SPS 74589) still had cadmium present on most of the threads and on more than 75% of the head. Rusting and slight pitting was evident under the head where contact with the bare steel track was made and where a corrodent would have a good chance of remaining because of capillary action.

The A-286 alloy bolts (SPS 74589CD) used in the same application appeared to be rusty but were not. Besides losing the cadmium all over the head and partially on the threads, they were undamaged.

B. PROCEDURES.

1. Design Improvements. The use of sealants has been advocated as a method to reduce corrosion for some time. Aircraft are literally covered with it but are not disassembled like the catapult system. Nevertheless, there is a place for sealants and some areas in the steam catapult are good candidates. Some trials have been conducted with aircraft type polysulfide sealants where the viscosity in cold weather makes it difficult to work with. Generally, sealants are for permanent applications and should not be used where they will normally extrude out. A few possible applications for these products are:

a. Bridle Arrester Track. The bridle arrester track sits directly on the steel track cover as shown in Figure 1 and is bolted to it. Liquid corrodents are able to seep underneath it as well as down into the bolt holes as shown in Figure 2. If the track were sealed to the track cover, removal would be more difficult but replacement at sea would probably not include a resealing effort. Thus, the initial effort would be in vain. If the track were in two pieces as in Figure 3, where the bottom piece was sealed permanently to the track cover by a wet sealant, liquids would not be able to get to the blind holes as easily. If the bottom piece is Teflon coated before sealing, removal can be expedited.

b. Stainless Steel Inserts. The substitution of a stainless insert for a tapped alloy steel blind hole provides corrosion resistance

as well as increased strength. If a deep insert is used, additional threads are available for a longer length bolt as shown in Figure 4. The interface between the insert and the enlarged hole should be sealed to eliminate galvanic corrosion.

c. Bridle Arrester Track Bolt. The addition of a sealant to the conventional socket head or external wrenching head should aid in reducing corrodent seepage. However, if a countersunk design were incorporated as shown in Figure 5, a Teflon coating would be more compatible and should facilitate sealing of the joint. Even if sealant was applied over the Teflon and was subsequently removed during maintenance, the more permanent Teflon could still provide sufficient sealing to prevent seepage.

The redesign of the bridle track bolt as shown above, can be carried a few steps further by incorporating features which provide convenience. The addition of a dual drive, locking device on the threads, o-ring seal, Teflon coating, removable cover plate, and squeezable void filler all help to improve the performance. These features are illustrated in Figures 6 through 9. The overall dimensions for the proposed dual drive bolt are shown in Figure 10. An internal hex drive coupled with an external 12-point drive serves as an alternate means of installation and removal. The hex recess is easier to manufacture than a square drive and will result in an economical saving. The countersink is an optional feature, but one which will provide improved corrosion protection to the joint.

d. Optional Bolting in Materials for High Temperature Flanged Joints. The harsh environment coupled with the elevated temperature requirements of 650 F indicates a need for a high temperature corrosion resistant alloy. A moderate degree of strength is required along with the aforementioned properties. Originally, in the proposal to this contract, A-286 was thought to provide all of the characteristics necessary. However, it was quickly determined that it would lose its preload when the system reached operating temperature. A number of other materials were considered for the application and a detailed set of calculations were required to generate the appropriate relationships so that an accurate assessment of applicability could be made.

The calculations follow along with a summary in Table I showing that Inconel 718 and MP159 come closest to matching the 4130 steel flange. The worst alloy is A-286, followed by MP35N and Waspaloy. The highest clampup is with PH13-8Mo, a martinsitic stainless steel.

In terms of recommending an alloy, the Inconel 718 is highest on the list because of its excellent corrosion resistance both general and in crevices. It is quite resistant to stress corrosion cracking and hydrogen embrittlement, also.

e. Effect of Temperature Change on the Preload of a Flanged Bolt. This analysis (Appendix A) takes into account the thermal expansion of both the bolt and joint materials as well as the change in Young's Modulus with temperature of both materials.

f. Effect of Plating Thickness on Shear Areas of Threaded Fasteners. In an effort to improve corrosion resistance of bolts and nuts, consideration has been given to increased plating thickness. While thicknesses are normally below 0.5 mil, threads can be "sized" to allow heavier coatings. Tables and figures were generated which show the effect of plating thickness on thread dimensions and the resulting change in shear area of the engaged bolt and nut.

Tables II through IV give dimensions for three bolt sizes while Tables V through VII give the effect of the thread dimensions on the shear area. Figures 11 through 16 show the effect of the plating thickness and thread engagement on the shear area of the threaded members. Finally, in Table VIII, the maximum shear area loss as a function of plating thickness is shown.

2. Exposure Program - Deck Bolts.

a. Screening Test Specimen Design. The design of a suitable specimen for representative joints of the catapult track cover was patterned after the T-rail and bridle arrester applications where the bolt is clamping dissimilar metals together and is subject to corrodent contamination from more than one direction. A typical area of the track cover involves a bolt joining two metals as shown in Figure 1. The bolt head is usually recessed and the threads may or may not be in a blind tapped hole. The bridle arrester track is a good example of galvanic incompatibility and is illustrated in Figure 2. The corrodent enters the joint from three directions and eventually finds its way into the tapped hole where it collects and causes severe degradation.

A simple but suitable specimen design which allows top and side entry of corrodents was fabricated from the alloys normally used aboard the carrier. This specimen, shown in Figure 17, consists of an upper bushing made of 304 stainless steel, AISI 4340 alloy steel or manganese bronze, and a lower blind tapped bushing made of 1018 steel. The upper bushing has a counterbore to accommodate the bolt head with ample clearance for corrodent to collect. It was tapered at its lower end to allow liquid to accumulate at the corrodent entry slot of the lower bushing.

b. Coating Selections. Twenty five coatings were screened, including both organic and inorganic compounds. Those selected for the track application required temperature capabilities of 250°F. They are described in Table IX.

The coating selection included several candidates unknown for fastener use along with a number of combinations thought to provide useful properties. Little attention was given to economic considerations or dimensional control, both of paramount importance for the final inspection. In addition to those coatings listed in Table IX, a number of metal coatings to be applied by metal powder or wire spray were considered by NAEC. However, these were not received in time to be included in the selection for the long term test.

c. Coating Application. Most of the electroplated coatings were prepared at SPS in commercial plating baths with recommended practices. The fasteners were mechanically blasted with 120 grit aluminum oxide and then plated according to applicable specifications, as listed below:

Plating Specifications

	Plating	SPS No.	Specification
1.	Cadmium + Iridescent Dichromate	P4	QQ-P-416, Type II
2.	Zinc + Iridescent Dichromate	P8	QQ-Z-325, Type II
3.	Dull Nickel	P12	QQ-N-290, Class 2
4.	Diffused Nickel-Cadmium	P24	AMS 2416

d. Coating Description. A description of the various coatings used is given below:

1. Electroplated Aluminum. This coating was provided by Ametek Electrochemical Development Labs in Sellersville, Pa. It is electrodeposited from an ether bath in barrels or by rack immersion. Alodine 1200S is a standard post conversion coating applied for most corrosion environments. Electroplated aluminum is a very pure metal and extremely susceptible to salt spray attack from the chloride ion. Being sacrificial as well, it is consumed rapidly in marine environments when coupled to more noble materials such as steel, stainless steel, and manganese bronze.

2. Flame Spray Aluminum. This coating was provided by the Naval Air Engineering Center and is similar to that developed by Metco, Inc. of Westbury, Long Island, N. Y. The coating was much too thick and spalled off the base metal during attempts to densify it and reduce its dimension. It was not tested. Much of the protection afforded by the coating, according to Metco, is a result of the generous thickness usually applied. Also, an oxide layer surrounds the aluminum metal and offers further barrier protection. The protection provided by thin coatings on the order of 1 mil or less is generally unknown but should be considered marginal at best.

3. Thermal Decomposition Aluminum. Xenoclad is the name given to this pure aluminum coating provided by TESCO of Houston, Texas. It is deposited by heating the sample to a temperature exceeding 600°F followed by quenching in an organo-aluminum liquid compound which decomposes. The coating is characterised by its complete coverage, even in deep recesses. However, being a pure aluminum, it is extremely susceptible to salt spray attack and is consumed quickly.

4. Cadmium and Nylon 11. This coating system is designed to provide sealing by means of the Nylon and corrosion protection from the cadmium. The latter was electrodeposited from a cyanide bath at SPS and the Nylon was electrostatically sprayed on at the Naval Air Development Center at Warminster, Pa. The Nylon is deposited as a powder which

requires an oven treatment to cause fusing. Small holes result here and there which allow the corrodent to penetrate and consume the thin cadmium layer. Ultimately, the cadmium corrosion products lift the Nylon allowing more corrodent to enter and rusting occurs. The Nylon seems to seal the threaded holes well, but it is applied so thick, the bolt is difficult to install and remove.

5. Cadmium. This coating was provided by SPS in the standard industrial thickness of 0.2 to 0.4 mil as well as 0.5 mil minimum. Cadmium is normally applied from a cyanide bath and requires baking at 375°F for periods up to 24 hours to relieve the plated hardware of embrittling hydrogen. Resistant to salt spray, cadmium plating of 0.5 mil thickness provides reasonable protection but of not a long enough duration. Thicker cadmium platings would be more pore-free as well as having additional sacrificial material. Because cadmium has good lubrication properties, it is advantageous to use for threaded fasteners.

6. Cadmium and Teflon. This coating system is designed to provide sealing by means of the Teflon and corrosion protection from the cadmium. The latter was electrodeposited from a cyanide bath at SPS and the Teflon was sprayed on and cured by SPS Western at Santa Ana, Calif. The Teflon provided minimal sealing action and proceeded to pop off, probably because of mechanical abuse and corrosion product formation under it. In order to be more effective, the Teflon should have adhered better to the cadmium and could have been applied somewhat thicker.

7. Cadmium and Sealant. This coating is designed to provide sealing by means of the polysulfide sealant (Products Research Corp. PRC-1436G) which was applied by SPS Western just under the head of the bolt. The cadmium plating was from a cyanide bath at SPS. The coating, which was cured before installation, offered no difficulty during installation.

8. Cadmium and Chromate. This coating is designed to supply ample quantities of soluble chromates in addition to sacrificial protection by means of the cadmium. The strontium chromate is well known for its corrosion inhibiting properties, especially with aluminum structures.

9. Cadmium and Zinc. This coating system provides cadmium which is resistant to marine environments and zinc which is resistant to industrial environments. Both metals are electroplated from cyanide baths and require baking to relieve the fasteners from hydrogen embrittlement.

10. Coricone 800. This coating is a black organic paint-like coating, capable of resisting outdoor environments as well as a number of chemicals. It was applied by Corro Therm, Inc. of Croyden, Pa.

11. Diffused Nickel-Cadmium. This coating system was developed for high temperature applications up to 900°F. It was applied at SPS by first depositing nickel from a sulfamate bath followed by cadmium from a cyanide bath. The two layers were then diffused at 630°F for 1 hour. AMS 2416 is the applicable specification number.

12. Nickel and Cadmium. This coating was applied at SPS and is intended to provide sacrificial action and barrier protection. The nickel was deposited from the sulfamate bath followed by the cadmium from a cyanide bath at SPS.

13. Nickel and Electroplated Aluminum. This coating system employed sulfamate nickel plated at SPS followed by electroplated aluminum provided by Ametek of Sellersville. The aluminum provided sacrificial protection and the nickel provided barrier protection.

14. Nickel and Thermal Decomposition Aluminum. This coating system was designed to provide noble metal barrier protection along with sacrificial action. The sulfamate nickel was deposited at SPS and the Xenoclad aluminum was applied by TESCO of Houston, Texas.

15. Nickel and Zinc. This coating system was applied by SPS from a sulfamate nickel bath and a cyanide zinc bath. The nickel provides a berrier while the zinc offers sacrificial protection.

16. Nickel. This coating is a thick sulfamate nickel plating (0.5 mil) applied by SPS unlike many of the thinner nickel base coatings utilized in this program. It offers pore-free noble barrier protection.

17. Nickel and SermeTel W. This coating system employs a thin coating of sulfamate nickel applied by SPS over which is a layer of SermeTel W, applied by Corro Therm, Inc. of Croydon, Pa. The former coating provides barrier protection while the latter supplies sacrifical action.

18. SermeTel W. This coating, applied by Corro Therm, Inc. of Croydon, Pa. provides sacrificial and thermal protection in corrosive environments. It was applied and cured according to AMS 2506.

19. SermeTel 554. This coating system employed a thin sulfamate nickel layer provided by SPS followed by a layer of SermeTel 554 applied by Teleflex, Inc. of North Wales, Pa. The latter coating is supposedly more sacrificial than SermeTel W.

20. Urethabond. This coating is a urethane paint, applied by Corro Therm, Inc. of Croydon, Pa. Topcoat formulation U-100 was applied over base coat formulation U-107. The system is said to be resistant to a number of chemicals. Although it is a metallic-looking paint, the Urethabond offers protection because it is fairly thick and provides a sealing action.

21. Zinc. This coating was provided by SPS in the standard industrial thickness of 0.2 to 0.4 mil as well as 0.5 mil minimum. Zinc is normally applied from a cyanide bath and requires baking at 375°F for periods up to 24 hours to relieve the plated hardware of embrittling hydrogen.

22. Zinc and Teflon. This coating system is designed to provide sealing by means of the Teflon and corrosion protection from the zinc. The latter was electrodeposited from a cyanide bath at SPS and the Teflon was sprayed on and cured by SPS Western at Santa Ana, Calif.

23. Zinc and Cadmium. This coating system provides cadmium which is resistant to marine environments and zinc which is resistant to industrial environments. Both metals were electroplated from cyanide baths at SPS and required baking to relieve the fasteners from hydrogen embrittlement. The combination of sacrificial coatings protected the threaded holes but did not offer much protection for the bolt area exposed to the environment.

24. Tin - Cadmium. This coating system provides sacrificial protection and no hydrogen embrittlement due to processing. It was applied by the 3M Co. of St. Paul, Minn. by a cold welding process where the fasteners are tumbled with the coating material, other chemicals, and a tumbling media to aid in deposition. The thickness was several mils, which caused minor problems with thread engagement. Regardless, the threaded bushing holes were rusty, indicating the non-anodic or sacrificial position of this coating with respect to the steel. The bolt surface exposed to the environment was also rusty, supporting the other evidence.

All of the screening program coatings except one were usable without further processing. The wire-sprayed aluminum was very thick (10 mils or more) and required a reduction in order to obtain clearance for thread fit. Accordingly, a device called a "Fette Head" was employed to roll the coating with applied force in order to densify it. However, instead of producing a more dense coating, it caused the coating to spall off the threads in pieces, leaving bare spaces.

Examination of the treated pieces revealed little or no adhesion to the sprayed coating. Thus, the rolling operation merely encouraged lifting of the coating by deformation, rather than tearing it off. Subsequent lifting or peeling was also accomplished by the use of a knife blade on areas not in contact with the "Fette Head".

The densification process is judged possible but difficult in view of these efforts and would require extensive work to improve the methods required to provide a coating worthy of consideration.

e. Coating Thickness. In most cases, coating thickness was determined by thread gage measurements, as is the usual practice. Spot checks were made on flat surfaces with a Magne-gage to insure the adequacy of the coating thickness.

f. Assembly. All of the upper and lower bushings were thoroughly degreased before installing the coated bolts and torquing to 600 inch-pounds.

g. Exposure. The low temperature screening test was conducted in a 5% salt spray cabinet operated per ASTM B117-64. The temperature was approximately 95°F and the specimens were mounted in a vertical position on PVC tables 8 inches from the bottom of the cabinet. The environment

was maintained constant for a period of 2000 hours, except for periodic 5 minute observations and removal of half the specimens after 1000 hours exposure.

h. **Long-Term** Exposure. The selection of the best coatings from the screening test for a long-term simulated exposure at Ocean City, N. J. depended on a simple but agressive specimen design, where excessive corrodent entry was provided for both the high and low temperature applications. In order to survive a much longer test period under more realistic conditions, specimens were designed to be accommodated in existing but proven facilities.

One of the test facilities, located at Ocean City Research Corp., is a turntable with programmed heat and corrodent sources. The turntable can accomodate up to 18 specimens approximately 4 inches square. The specimen was kept as small as possible while still employing large diameter bolts. Three different top plate materials were used, as in the screening test, along with HY80 steel for the bottom plate as shown in Figure 18.

Because of the three different top plate materials and the 18 specimen capacity of the facility, only six assemblies of each top material could be employed. Therefore 12 coatings were selected, each to share half the space on a specimen block. The 12 coating systems selected were on the basis of performance, commercial availability and dimensional control. They are listed in Table X.

The conditions employed for the long term test are shown in Table XI.

3. Exposure Program - Flange Fasteners.

a. Screening Test Specimen **Design**. The elevated temperature specimen, designed to simulate a steam pipe flange, consisted of a metal cylinder with a "window" for corrodent entry, a stud 3 inches long and hex nuts to apply a load. It is shown in Figure 19. The cylinder was made from AISI 4130 steel, the alloy currently used for steam pipes. The stud material was MIL-S-1222, a high temperature alloy currently in use for this application without benefit of a coating. The nut material was the same as the stud. Nuts were obtained through the Naval stock system.

This simple design, without a gasket, allowed for tightening the joint just as in the actual application, although greater access of the environment to the fasteners was provided in this test. The normal application employs lagging which insulates the pipe but also gets soaked with corrodents seeping in from the deck above.

b. Coatings A list of the coatings for the high temperature test is given in Table XII, where only eight systems were evaluated, owing to the absence of the noble metal powder and wire spray coatings mentioned earlier. One of the systems tested was Inconel 718 studs and nuts. This is an alloy capable of 220,000 psi strength level, exceptionally good corrosion resistance, and a temperature capability in excess of 700°F.

A second screening test was run with the same coating systems employed on the studs and nuts, but the steel cylinders were coated by NAEC with the

Metco 120 system of wire sprayed aluminum.

c. Exposure. The elevated temperature application was simulated by a severe test consisting of 8 hours at 700^{+20}_{-0}°F followed by 16 hours in 5% salt spray. This cycle was repeated 10 times, except for weekends when the specimens remained in the salt spray. The specimens were exposed to a total of 80 hours at 700°F and 256 hours of 5% salt spray.

d. Long Term Exposure. The long term, high temperature test required a specimen resembling two pipe flanges with a gasket sandwiched between them as well as an ample heat source to maintain a 700°F temperature of the joint. Large diameter studs and nuts were employed to provide high clamping forces. The specimen design is shown in Figures 20 and 21. These specimens were encapsulated in cocoons of lagging material and exposed to a mixture of corrodents by means of periodic injection.

The coatings tested are shown in Table XIII and the conditions used are shown in Table XIV.

4. Exposure Rack. The trial exposure of coated studs and nuts in the launch valve room was of interest to determine how corrosion generated there would compare to that generated in the long term high temperature exposure program.

a. Design. A rack constructed of steel angle fastened together with the test studs and nuts was designed as depicted in Figure 22. This rack was welded to the wall of the launch valve room by means of a suitable bracket and was covered with the pipe lagging normally used. Full scale drawings of the rack components are given in Figures 23 and 24.

Studs of 3/4 inch diameter are spaced along the length of fastened right angle so that ample space is available for wrenching.

b. Coating Selection. Since 12 fastening systems could be employed, only 6 coating conditions were selected so that some would be in the horizontal position and some would be in the vertical position. In addition to the bare condition and an Inconel 718 system only 4 coatings thought to be economical enough for use were selected as shown in Table XV.

c. Assembly. All of the studs and nuts were coated with MIL-L-46010 (MR) (Sandstrom 9A) inhibited dry film lubricant on all threaded areas and bearing faces before assembly. Sufficient torque was employed to squeeze the angle iron completely together. Steel spacers were used to effect a finite separation of 1/16 to 1/8 inches.

End brackets of 1/4 inch thick steel were welded to the rack so that the bracket could easily be tack welded to the launch valve room wall.

d. Exposure. The two racks were sent by NAEC to aircraft carriers in two different parts of the world. One was sent to the U.S.S. Saratoga in the Mediteranean and the other to the U.S.S. Ranger in the Pacific. The racks were exposed on the launch valve room wall for approximately 6 months before being sent back to NAEC for evaluation.

5. Metal Sprayed Bolts. A large quantity of alloy steel socket head cap screws was supplied to NAEC for coating with various metal systems. These coating systems were applied by a vendor and returned to SPS via NAEC. Representative samples were hung in a 5% salt spray cabinet by means of nylon monofilament until at least 50% of the surface was rusty. Table XVI gives a list of the coatings.

The thickness was much greater than the 2 or 3 mils requested. This characteristic did not permit the use of mating nuts or tapped holes to be used in conjunction with the bolts.

6. Electrochemical Tests. Electrochemical potential and polarization measurements were made in order to quantify the performance of candidate fastener coatings. The measurements were made on each coated fastener in sea water prior to exposure, midway through the exposure test, and at the end of the exposure test. Only the threaded area of the fastener was included in the measurement. The remainder of the fastener was masked with epoxy. The polarization measurements were non-destructive and allowed accurate direct calculations of corrosion rates for the metallic coatings.

The basis for using calculated corrosion rates to evaluate coating performance can be seen by examining the characteristic manner in which a sacrificial type coating behaves in an aqueous environment. If a metallic coating were applied perfectly to the substrate metal, it would be pore free and would corrode at a rate characteristic of the coated metal, itself. However, no coating system can be considered pore free and, therefore, the calculated corrosion rate is a summation of both the local action corrosion rate for the metal coating and the galvanic corrosion rate caused by local bi-metal cells between the substrate metal and the coating. The number and intensity of localized bi-metal cells on the coated surface is a direct function of the porosity of the coating. Because the porosity of a metal coating increases as the metal corrodes or sacrifices, the corrosion reaction becomes self stimulating. Polarization measurements allow calculation of the changing corrosion rate as a function of time. From the corrosion rate vs. time data, meaningful extrapolations can be made allowing prediction of the useful service life for individual coatings. This is simply not obtained by other methods.

Corrosion rates of metals in aqueous environments are determined by polarization measurements, according to the Stern and Geary equation:

$$I_c = \frac{1}{2.3} \times \frac{B_a \times B_c}{B_a + B_c} \times \frac{\Delta 1}{\Delta \phi}$$

where I_c = local action corrosion current density
B_a = Anodic Tafel Slope
B_c = Cathodic Tafel Slope
Δ = impressed current density
$\Delta\phi$ = polarization caused by impressed current, when $\Delta\phi < 20$ millivolts

The corrosion rate is a linear function of Ic according to Faraday's Law:

$$\text{Corrosion rate} = \frac{kIc}{P}$$

where k = electrochemical equivalent for specific metal
P = density of specific metal

For a given metal, Ba and Bc are relatively constant. In order to experimentally determine a corrosion rate, it is necessary only to measure the quantity $\frac{\Delta I}{\Delta \phi}$

Electrical potential measurements also provide meaningful data for evaluating the performance of a sacrificial type coating. Initially, the base metal with a sacrificial type coating would be expected to exhibit an electrochemical potential characteristic of the coating metal in the particular aqueous solution. As the metal coating is sacrificed, the potential will change toward a value more characteristic of the base metal that the coating. Potential measurements with time will give a meaningful indication as to the performance of a sacrificial type coating.

Although a typical environment is often more atmospheric than total immersion, polarization and potential measurements in sea water provide semi-quantitative performance data. The calculated corrosion rates in sea water are not, of course, identical in magnitude to the corrosion rates that occur in the atmosphere. However, changes in the sea water corrosion rate or sea water potential as a function of time provide quantitative evidence of how a metal coating is performing in the atmosphere. These changes in the characteristic properties of the coating may not be obvious by physical inspection.

Newly coated screws and previously exposed screws were subjected to the electrochemical test described above in order to measure corrosion rates and corrosion potentials.

C. RESULTS.

1. Low Temperature Screening Test. Observations of all low temperature specimens immediately after removal from salt spray revealed gross corrosion of the lower tapped bushing and excessive quantities of corrosion products elsewhere. Thus, nothing significant could be determined until this debris was removed and the specimens were disassembled. Extensive cleaning was required of practically every component with soap, water, and brass bristle brushes. After this treatment, the specimen pieces were dried with compressed air, identified, and stored.

Examination was made visually with and without the aid of a 60X Stereo zoom microscope. Comments relative to the appearance of the specimen components are noted in Table XVII.

2. Low-Temperature Long-Term Salt Spray. After 1000 hours of 5% salt spray exposure at SPS, the specimens were removed, cleaned and examined. The results of this examination are shown in Table XVIII.

3. Long-Term Low-Temperature Test. The Ocean City exposure specimens were examined after 2 1/2 months on the test rig. Table XIX shows the results of the examination at this time.

After 4 1/2 months on the Ocean City test rig, an examination produced the results shown in Table XX. After 7 months of exposure, the results shown in Table XXI were observed. At the completion of 9 months of exposure, an examination produced the results shown in Table XXII, and Photographs 1 through 22.

4. High Temperature Screening Test. The results of the elevated temperature test are shown in Photographs 23 through 30. An unexposed stud and nuts, the assembled and exposed joint, and an exposed stud and nuts are seen in each picture.

The electroplated aluminum is completely gone and severe rusting has occurred. The nickel remaining under the electroplated aluminum in the next system offers little additional protection. The diffused nickel cadmium coating permitted thread rusting to occur, but the thick nickel coating in the next system provided excellent protection.

The nickel flash and SermeTel 554 allowed slight rusting to occur, while the nickel flash and SermeTel W showed more extensive rusting, including a "frozen" nut on one stud. SermeTel W did not prevent rusting but kept it to a minimum. The best system was the Inconel 718, whose surface darkened due to a thermal oxide, but remained virtually unattacked otherwise.

5. High Temperature Screening Test - Second Run. The results of this exposure are shown in Figures 31 - 38.

In all cases, the studs and nuts appeared much better with the aluminum coated cylinders than with the previously tested bare steel cylinders.

The electroplated aluminum has some white corrosion products on the threads of the studs and nuts. No rusting was observed except on the steel cylinder emanating from the inside where the surface was probably bare. The cylinder faces were relatively clean and not significantly corroded.

The addition of electroplated aluminum over electroplated nickel did not aggravate the cylinder face condition although red rust was found exuding from the inside of the cylinder. The stud and nuts were also in excellent condition with no red rust present and only a small amount of powdering white corrosion product.

The stud with the diffused nickel-cadmium coating exhibited rust-like stains on its center section which were probably from the insides of the cylinder. The nuts had white corrosion products on the threads. However, ther was some evidence of galvanic consumption of the aluminum coating on the cylinder under the nut bearing face.

Electroplated nickel appeared unscathed on the stud and suffered from minor rusting in the threads where thickness was reduced due to throwing power losses. The cylinder was white with corrosion products but was not

attacked any more than with the diffused nickel-cadmium coating.

No rusting was observed for the studs or nuts coated with nickel and SermeTel W although appearance indicated the partial depletion of the top-coat in some areas. The inside of the cylinder was rusty which spread to the outside and the ends under the nut bearing surface were not significantly attacked but merely darkened.

The SermeTel 554 had a little more white corrosion product than the previous coating but appeared healthy otherwise. The nuts exhibited corrosion product buildup on the bearing face and a small amount of rusting. The cylinder rusted internally and the bearing faces were attacked slightly.

The SermeTel W allowed rusting to occur on the stud and nut threads. Depletion of the coating was evident on the smooth shank portion. The cylinder exhibited rusting internally and attack under the nut bearing face.

No attack of the Inconel 718 bolt or nut was observed. The cylinders were rusty internally and had white corrosion products all over but were not significantly attacked on the bearing ends.

6. Long Term High Temperature Test. After 6 weeks of exposure, the cocoons were cut open and the metal specimens examined. After 15 weeks of exposure, the cocoons were cut open and the metal specimens re-examined. Results of these examinations are shown in Tables XXIII and XVIV.

After 9 months of exposure, the specimens were removed, cleaned up and examined. Comments are shown in Table XXV and Photographs 39 - 58 are provided for visual evidence.

The fasteners were disassembled and the breakaway torques measured as recorded in Table XXVI.

7. Exposure Racks. The rack from the U.S.S. Saratoga was returned first and photographed after cleanup as shown in Photographs 59 - 64. The rack from the U.S.S. Ranger was not as corroded as that from the U.S.S. Saratoga. Both racks were completely disassembled and the fasteners cleaned up before further examination.

Table XXVII lists the breakaway torques experienced for the various coating systems. Once broken away, the prevailing torque required to disassemble the joint had to be overcome. This value was significant where rusting had occurred, such as on the bare and electroless nickel conditions.

Table XXVIII lists the appearance of the various coating systems after they had been cleaned up.

8. Metal Sprayed Bolts. Table XXIX lists the results of 5% salt spray testing.

9. Electrochemical Tests. Tables XXX and XXXI present the data obtained initially and midway through the test exposure. The initial

data shows several things. First, the beneficial effect of the polysulfide sealant is quite obvious. The corrosion rate in sea water for the fasteners coated with sealant is an order of magnitude lower (0.027 and .39 mil per year) than all of the other coatings except for the SermeTel W. In essence, the polysulfide sealant acts as a barrier and effectively reduces the exposed metal surface area. This results in a lower measured corrosion rate. The SermeTel W coating also acts more as a barrier coating than a metallic coating and effectively reduces the area of exposed metal.

The electroless nickel coating exhibited a rather high initial corrosion rate (8.25 mpy), much greater than the electroplated nickel (1.03 mpy). The data indicates that the electroless nickel coating as applied is more porous than the electroplated nickel. On immersion of the electroless nickel coated fastener in sea water, rusting occurred immediately at numerous pinholes. The electroplated nickel fastener exhibited a negligible amount of rusting under the same conditions.

Initially, the cadmium coatings by themselves seem to corrode at about 5 times the rate of the zinc coatings in sea water. Zinc with a cadmium overcoat showed a lower initial corrosion rate than cadmium with a zinc overcoat. ($\simeq$ 1 mpy vs. 3 mpy).

The greater ability of zinc to cathodically protect the steel substrate was evidenced by its high initial potential ($\simeq$ - 1.02 V vs. Ag - AgCl). Examination of the data shows that a zinc coated fastener could easily be identified by simply measuring its corrosion potential.

Examination of the data obtained on the fasteners removed midway through the test shows dramatic changes in both corrosion rate and potential. Many of the fasteners exhibited much higher corrosion rates indicating that most of the coating is gone. The measured corrosion rate is more characteristic of the steel substrate. The measured potentials in these cases are also characteristic of steel in sea water. For some of the nickel coatings, the potentials are more noble than would be expected for steel, indicating that some nickel still remains. However, because nickel is noble to steel, high corrosion rates occur due to galvanic action.

In some cases, very low corrosion rates were measured. This might be the result of insoluble salt formation on some coatings. Even in these cases, the potentials seemed to move toward values more characteristic of steel. The most dramatic change in potential occurred for the zinc coating. Except for the zinc overcoated with polysulfide sealant, the potential of all zinc coatings increased to values more characteristic of the steel substrate. The beneficial effect of the polysulfide sealant is again demonstrated. It should also be mentioned that the fasteners with polysulfide sealant were by far the easiest to remove from the test plates and showed the least corrosion on the uncoated female threads.

In summary, the electrochemical data correlated well with visual observations and also provided quantitative support for rating coating performance. There appears to be some anomalies. In view of only three data points acquired for each fastener, the gathering of more data points would probably

resolve the anomalies and provide additional supplementary data as an aid in quantitatively rating coating performance. For the record, electrochemical measurements made after 9 months of exposure are shown in Tables XXXII and XXXIII. These tables show data for a bolt removed and reinstalled at the 4.5 month point as well as for a bolt removed only after the full 9 months of exposure.

D. DISCUSSION.

1. Deck Bolts. Of all the coating systems tested, three were considered clearly superior based on 9 month exposures and electrochemical tests. Two of the three were sacrificial metals overcoated with a polysulfide sealant. The third was a combination of two sacrificial metals.

In these three coating systems, only electroplated cadmium or zinc was employed, both of which are commercially available. The polysulfide sealant is a 2 part mix, prepared just before installation of the bolts for wet application. However, it can be applied on the bolts and fully cured before installation.

The cadmium plating protects the steel bolt and the threaded steel hole by sacrificial action. Therefore, when all of the cadmium is depleted in a given area, the bare steel causes the remaining cadmium to deplete even faster. The only way to get more protection for the bare steel is to put a longer lasting coating on top of it. This is achieved by a thicker sacrificial coating which will last longer but still will be consumed eventually.

Zinc, also a sacrificial coating, is consumed more rapidly than cadmium in a chloride environment because it is a more active metal and also because its corrosion products are more soluble and do not offer surface protection.

The coating system which had a base layer of cadmium and a top coating of zinc (No. 4) did not protect nearly as well as the opposite condition. The reason for this may be that the zinc topcoat depletes rather quickly and the remaining cadmium cannot adequately protect. On the other hand, if the cadmium is the topcoat and depletes much more slowly, a larger amount of sacrificial metal is available during the course of the exposure. This is probably the case with the coating system No. 12.

The polysulfide sealant is successful because it effectively prevents electrolyte from getting into the threads. Therefore, it works equally well over cadmium or zinc as evidenced by the results of this program. Unfortunately, it cannot be used to close up the recess in or around the bolt and therefore offers little protection to the head and drive.

Whether the sealant is applied wet or pre-cured, as in this program, it is capable of preventing the entry of contaminants into the joint. Therefore, it should also provide protection to the threaded hole even if the bolt is bare alloy steel. This high degree of protection in the threaded area should be matched by a similar high degree of protection on the bolt head.

Experience in screening tests and long term exposures has shown that sacrificial coatings, whether they be zinc, cadmium, or aluminum, cannot withstand the harsh deck environment as well as a more noble coating. Therefore, electroplated nickel in sufficient thickness has been shown to offer outstanding protection to the bolt head. The combination of nickel and cadmium in a diffused coating was shown to be not as good as cadmium in protecting the threads and no better than the nickel protecting the head.

Therefore, the coating system required for this application should be different in two separate areas. This coating technique is relatively expensive if masking is employed but relatively inexpensive if nickel is applied all over the bolt in a thickness sufficient to protect the head. Cadmium can then be plated over the nickel so that the threaded area will be sacrificial. If used in service in this manner, the cadmium on exposed surfaces, such as the head, will be consumed but the remaining nickel will protect by barrier action. Meanwhile, the nickel on the threads will cause minimal problems because there is sufficient cadmium over it to maintain a sacrificial quality as well as provide lubricity for torque requirements. When the cadmium is eventually depleted in the threaded area, the remaining nickel can cause galvanic attack. However, a periodic replenishment of cadmium plating over an undamaged nickel plated bolt would serve to restore the bolt to a "new" condition and guarantee additional corrosion-free life for the threaded hole. This technique will work only if a thick coating of approximately 1 mil can be tolerated on the threads.

If the nickel plating could do an excellent job of protection on the head and the sealant protects likewise in the threads, then it is conceivable that a nickel plated bolt, without cadmium, could be used with sealant for the bridle arrester track application. After all, if the sealant prevents corrodent entry into the threaded hole, how could galvanic action occur between the nickel and the bare steel?

In theory this is correct but in practice it can be shown that some bolts will be installed, perhaps in haste, without sealant, and corrosion will occur unchecked until the next regularly scheduled maintenance. The addition of the cadmium over the nickel can serve as "insurance" so that even if the sealant is not applied or is applied improperly, the presence of the cadmium will serve to sacrificially protect the threaded hole.

2. Flange Studs. The combination of elevated temperature and severe corrosive environment limit the number of coating systems applicable for this installation. Cadmium and zinc plating should not be used above 450°F because of the threat of stress alloy cracking. Aluminum plating or coating can be used but does not sufficiently resist the chloride ion with the relatively thin layer required on the threads. Without the three primary sacrificial metals, protection schemes fall upon the noble nature of nickel and chromium.

These coatings are barriers and protect only when they are thick enough to be relatively pore-free. This study has shown how electroless nickel deposits allowed rusting all over at the same thickness level where electroplated nickel was virtually completely protective. In order to provide a rust-free surface after exposure, a relatively thick coating of nickel (.0007") was employed.

Other coating systems evaluated or considered did not or could not withstand the harsh environment of the laboratory tests or could not be deposited according to the thickness requirements generally acceptable for fasteners. Where sacrificial type coating systems were evaluated, such as SermeTel W, it was found that corrosion products made it more difficult to remove the nut from the stud. In fact after a screening test, a SermeTel W coated nut could not be removed from the stud.

The best system tested was one in which both stud and nut were of corrosion resistant materials. In the laboratory tests, Inconel 718 proved to be an excellent choice and exhibited no attack. Even in the carrier exposure test, the Waspaloy nut and Inconel 718 stud were not visibly attacked. Thus, an "infinitely thick coating" (solid corrosion resistant alloy) has the ability to completely resist the environment without fear or worry of corrosion damage. Anything less resistant than an excellent corrosion resistant alloy may not provide the same results.

It must be understood also that corrosion resistant alloys other than Inconel 718 have to satisfy the physical requirements discussed in Appendix A pertaining to the effect of temperature on the preload. If an indiscriminate choice is made, the possibility exists of either losing the sealing action on the flange joint or exceeding the tensile strength of the studs. In both cases, a loss of steam will occur, although in the latter case, broken studs of large diameters could be flying dangerously through the compartment.

The galvanic corrosion between the nickel plated nut bearing face and the Metco 120 aluminum coated steel plate can be controlled by employing aluminum clad steel washers under the nut. This aluminum coating can be the Metco 120 system, SermeTel W, or Nickel + SermeTel W, Diffused Nickel-Cadmium, or a temperature resistant non-metallic coating can also be employed.

Another concept worthy of consideration is to use a high strength corrosion resistant alloy such as Inconel 718 in place of the current lower strength alloy steel but with a reduced diameter. This feature would make it practical to utilize existing holes by means of bushings and/or washers with protective coating. The reduced diameter corrosion resistant alloy studs would provide the same clamping force as at present with no requirement for a major design change.

It is interesting to note the good correlation between the laboratory tests and the aircraft carrier exposure, even though the latter was at launch valve room temperature and not at 700°F.

E. CONCLUSIONS.

1. The harsh environment present on deck and in the launch valve room as well as the limited maintenance provided at sea necessitates superior corrosion resistance for fasteners in order to remove and reinstall them.

2. Superior corrosion resistance for deck bolts can be provided by cadmium and/or zinc with thicknesses in the 0.5 to 1.0 mil range even though

some rusting will probably occur on the head during one tour of duty.

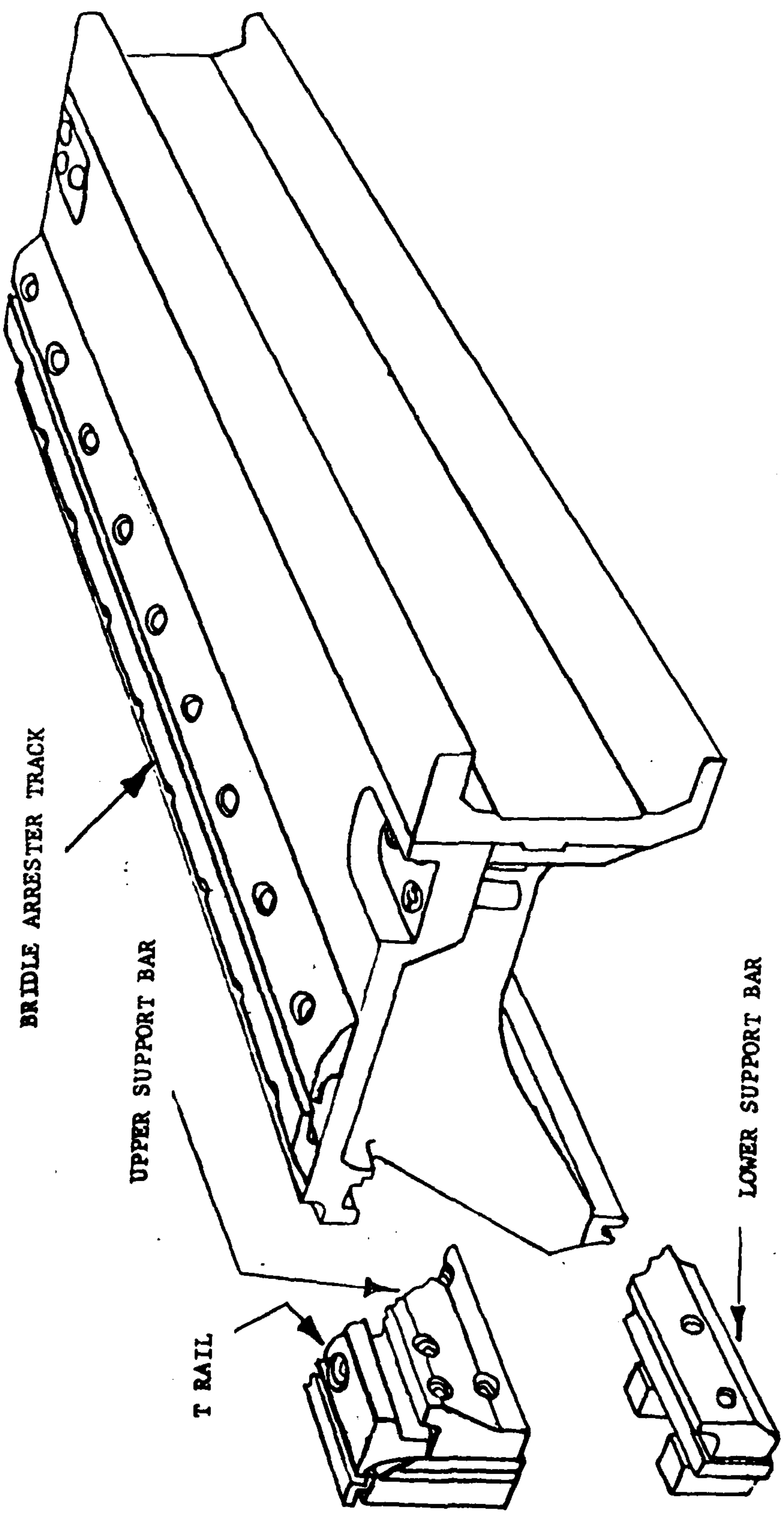
3. A polysulfide sealant, applied over a plated deck bolt and installed wet, offers the best solution to preventing severe corrosion in blind tapped holes.

4. Electroplated sulfamate nickel, with a thickness of at least 0.5 mil protects deck bolt heads better than the same thickness of cadmium or zinc.

5. Electroplated sulfamate nickel, with a thickness of at least 0.7 mil, protects launch valve flange studs and nuts better than any other coating system tested.

6. Inconel 718 alloy provides the best solution to preventing corrosion of launch valve studs and nuts.

7. Metal sprayed coating is not yet suitable for application on bolts without obtaining extremely thick coatings which cannot be tolerated or are too porous to provide barrier protection.



TYPICAL STANDARD TRACK COVER AND SUPPORT SYSTEM

Figure 1

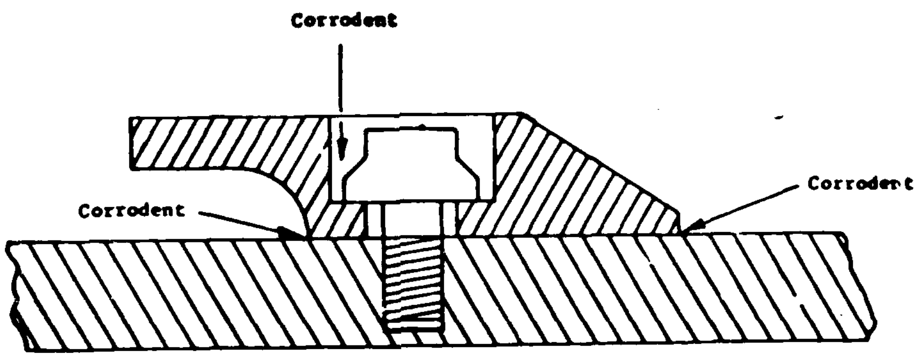


Figure 2. Existing Bridle Arrester Track System

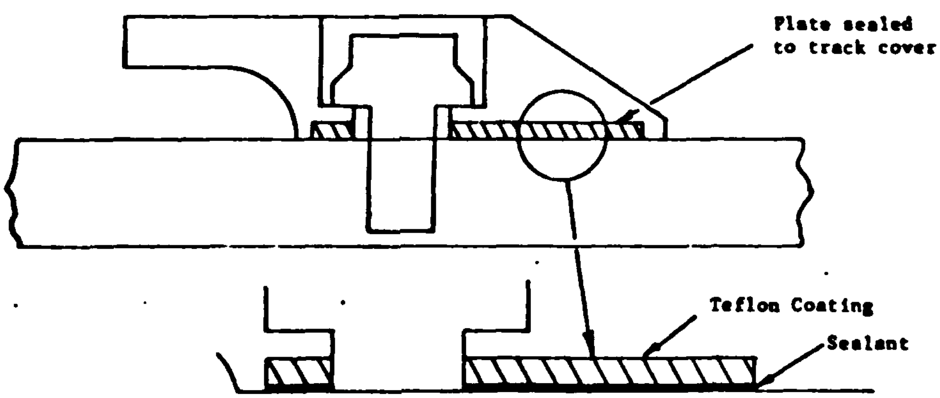


Figure 3. Proposed Two-Piece Bridle Arrester Track to minimize lateral seepage of corrodent into blind bolt hole

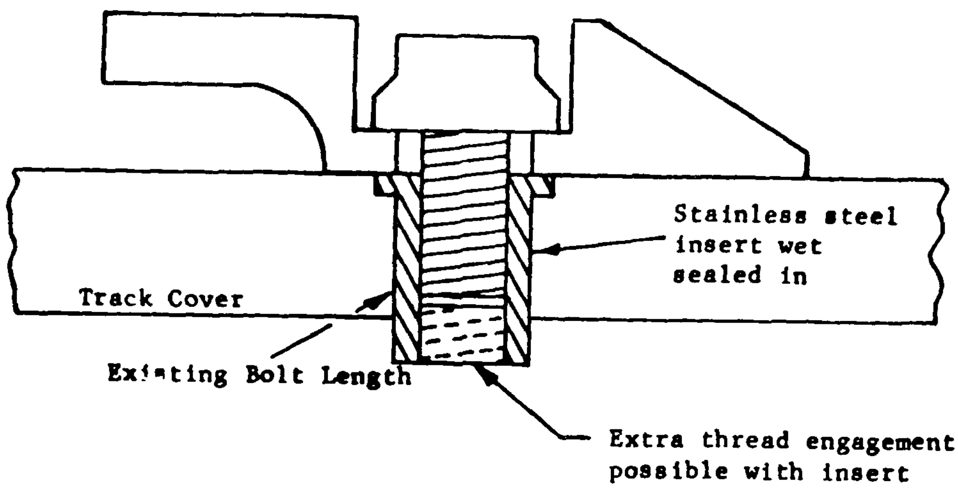


__Figure 4.__ Wet sealed insert provides extra threads and corrosion resistant installation.

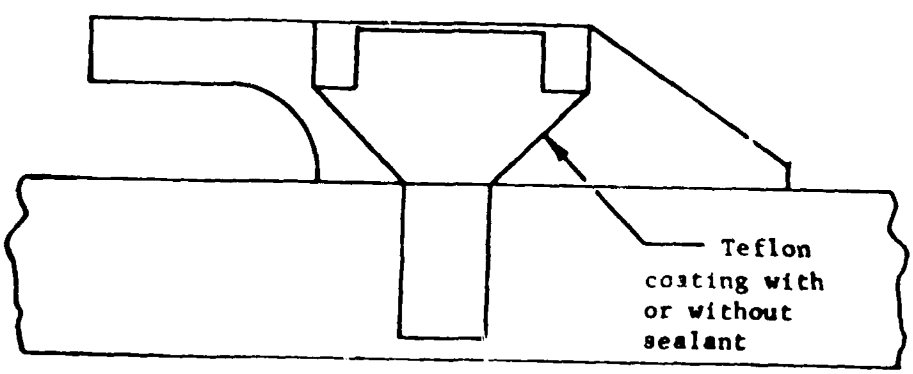


__Figure 5__. Proposed bridle track arrester bolt with countersunk head.

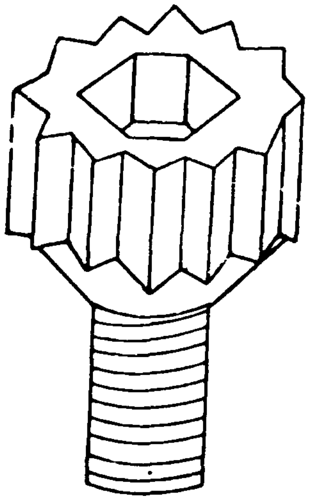


Figure 6. Dual Drive Bolt

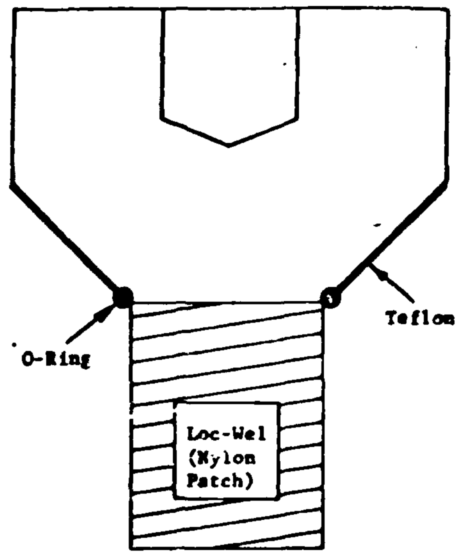


Figure 7. Locking and Sealing Devices

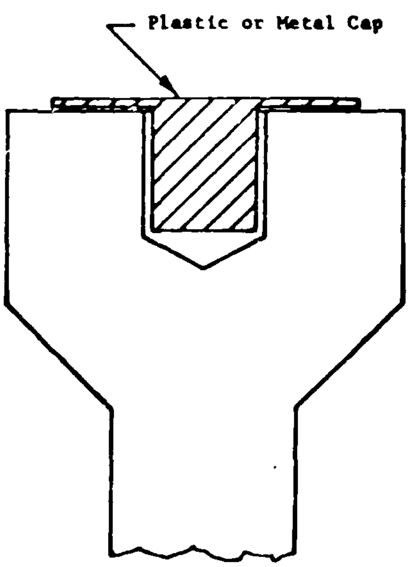


Figure 8. Protective Cap

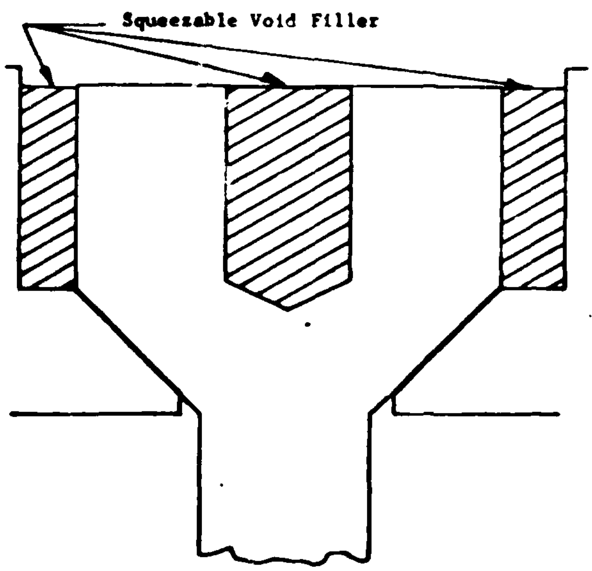


Figure 9. Sealing Device

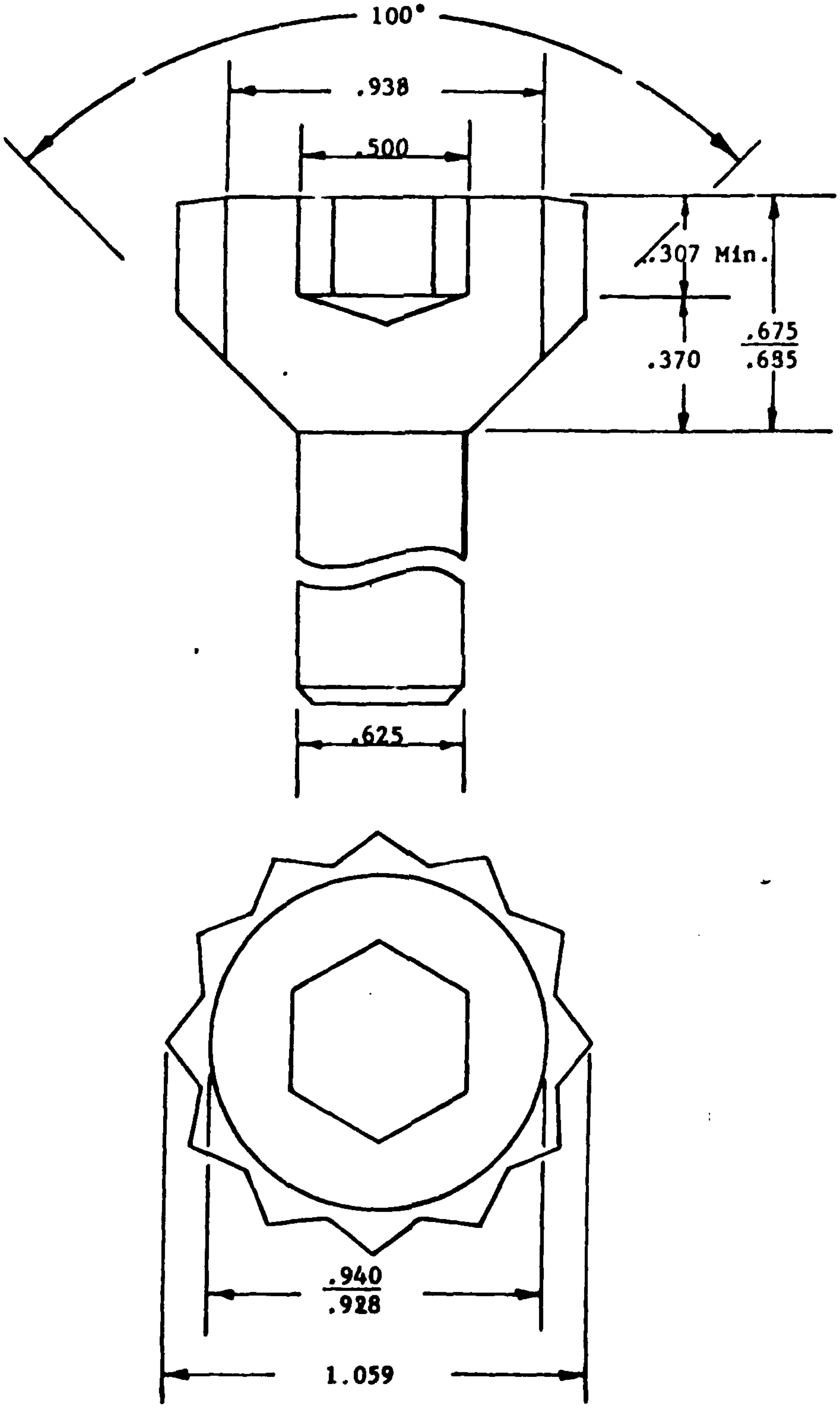


Figure 10. Dimensions of Proposed Dual Drive Bolt

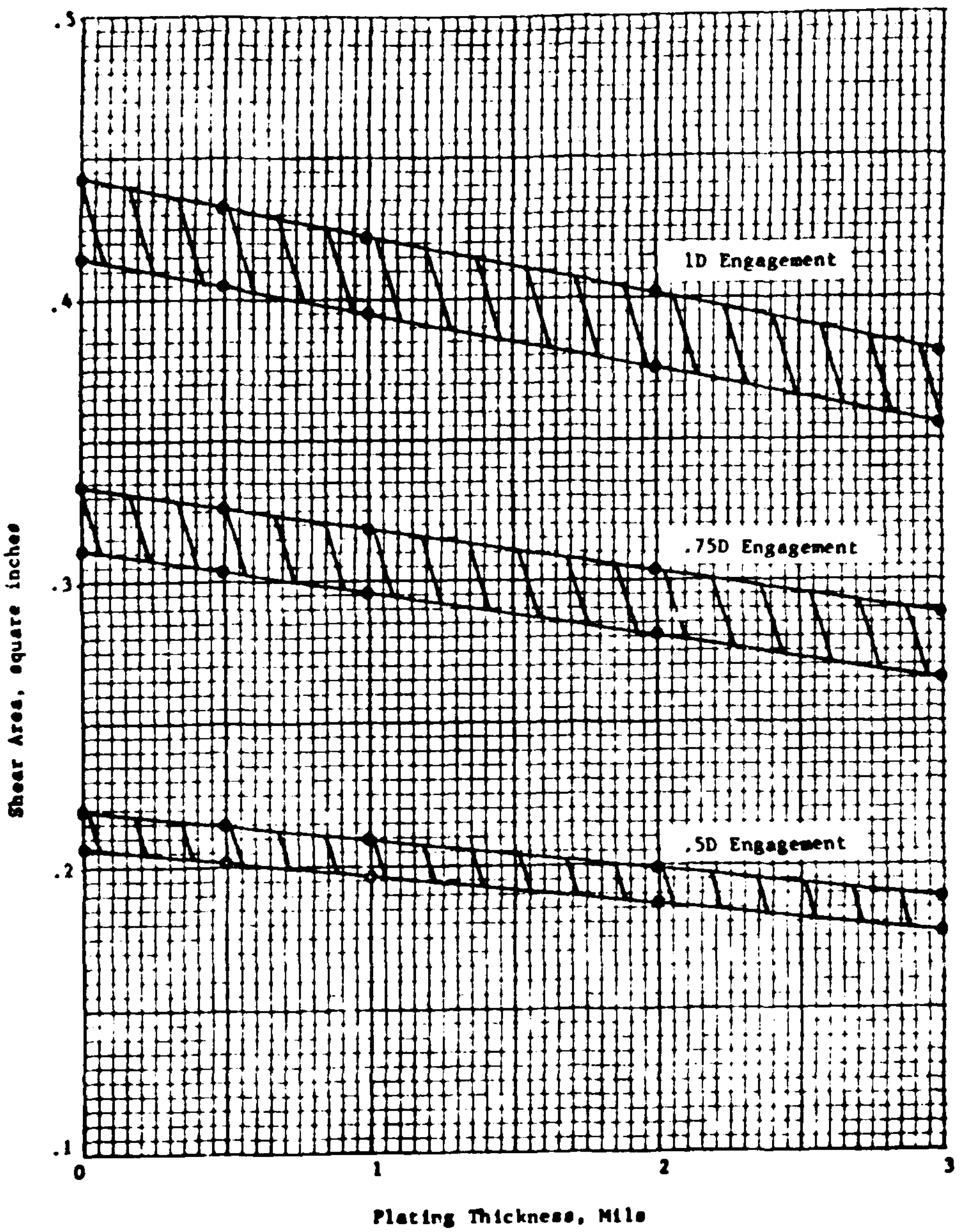


Figure 11. Effect of Plating Thickness and Thread Engagement on Shear Area of 1/2-13, Class 2, External Threaded Bolt or Stud.

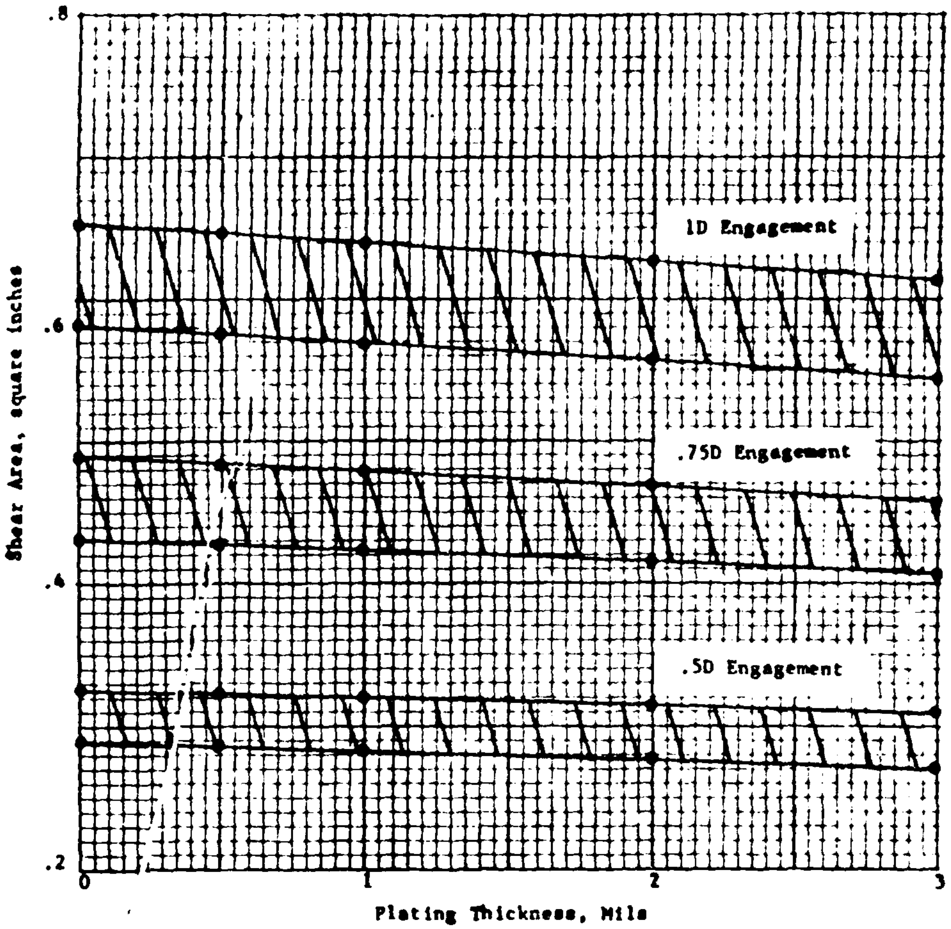


Figure 12. Effect of Plating Thickness and Thread Engagement on Shear Area of 1/2-13, Class 2, Internal Threaded Nut.

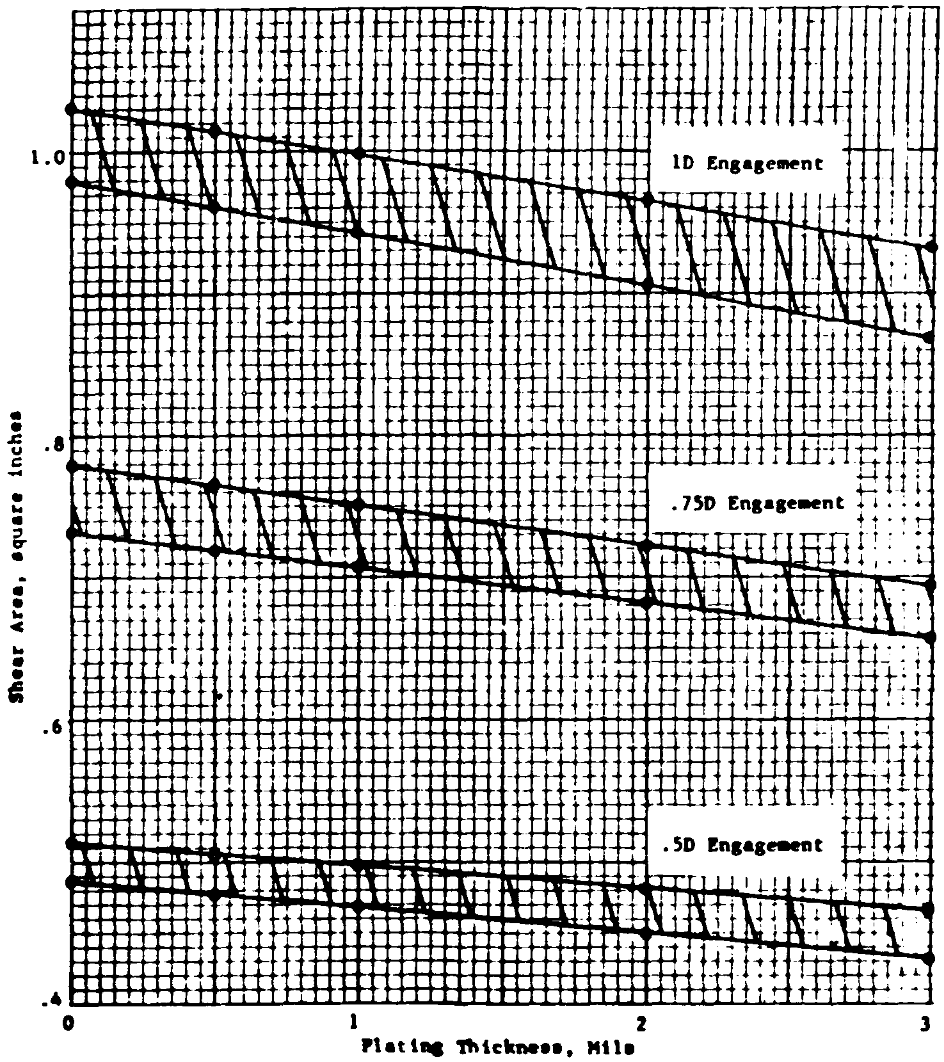


Figure 13. Effect of Plating Thickness and Thread Engagement on Shear Area of 3/4-10, Class 2, External Threaded Bolt or Stud.

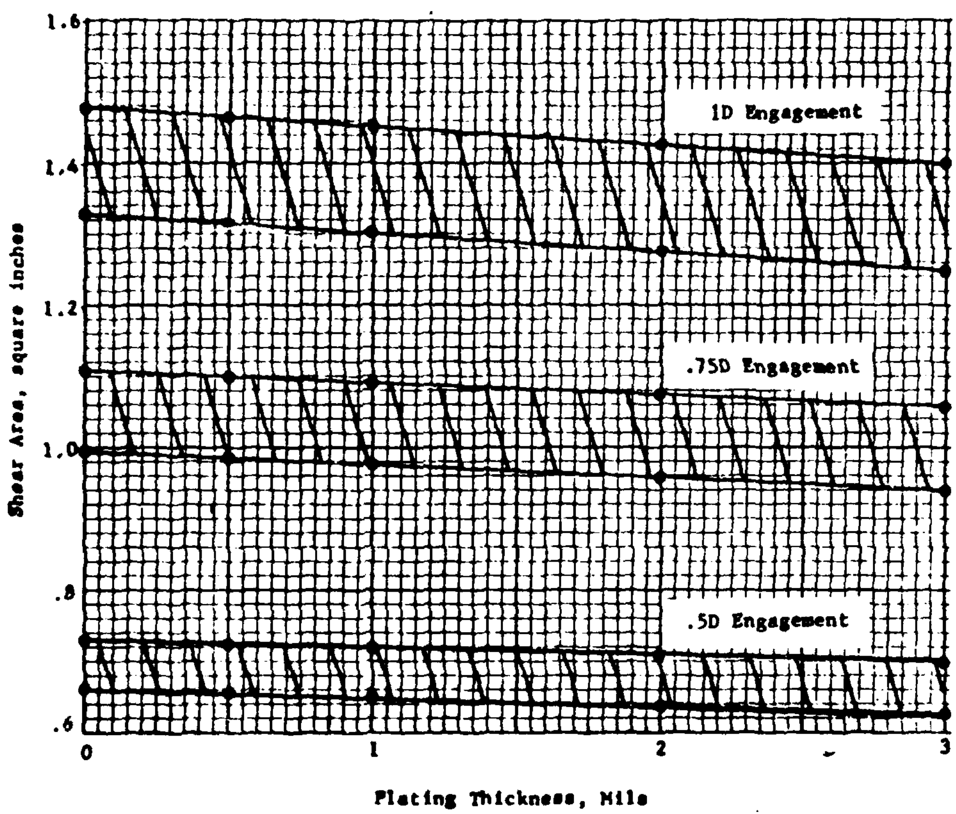


Figure 14. Effect of Plating Thickness and Thread Engagement on Shear Area of 3/4-10, Class 2, Internal Threaded Nut.

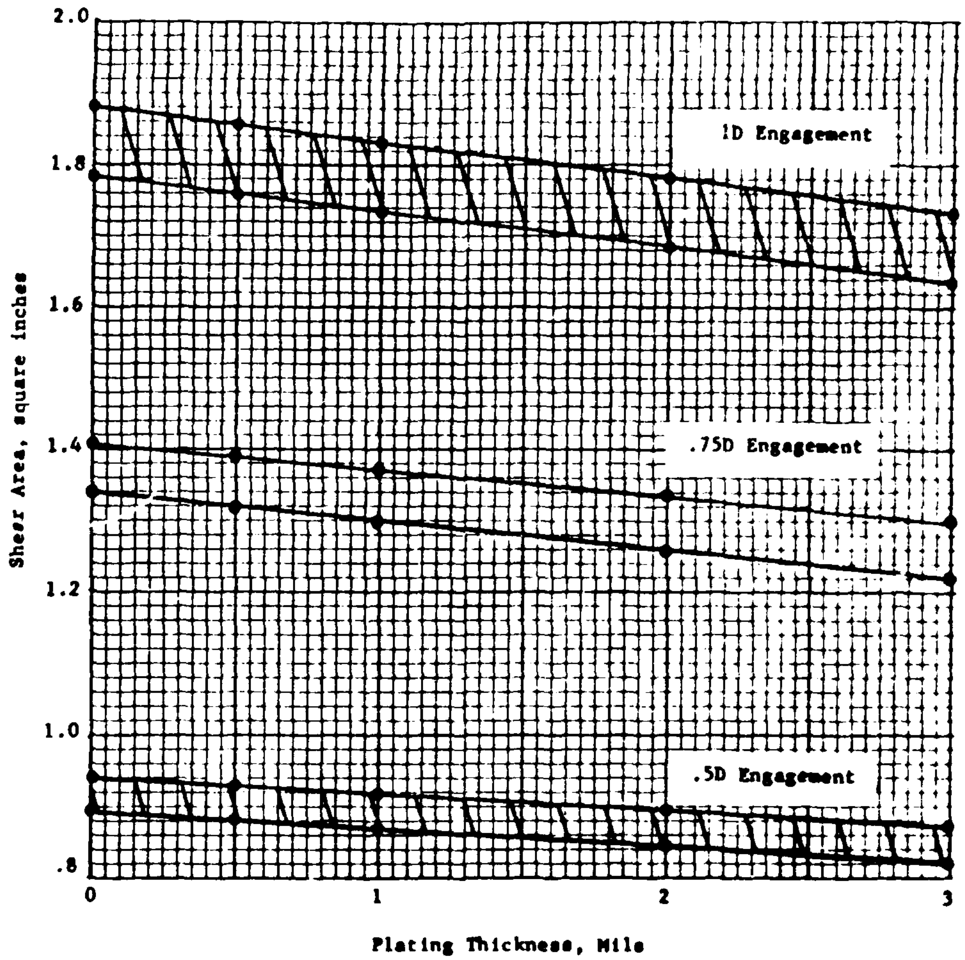


Figure 15. Effect of Plating Thickness and Thread Engagement on Shear Area of 1-8, Class 2, External Threaded Bolt or Stud.

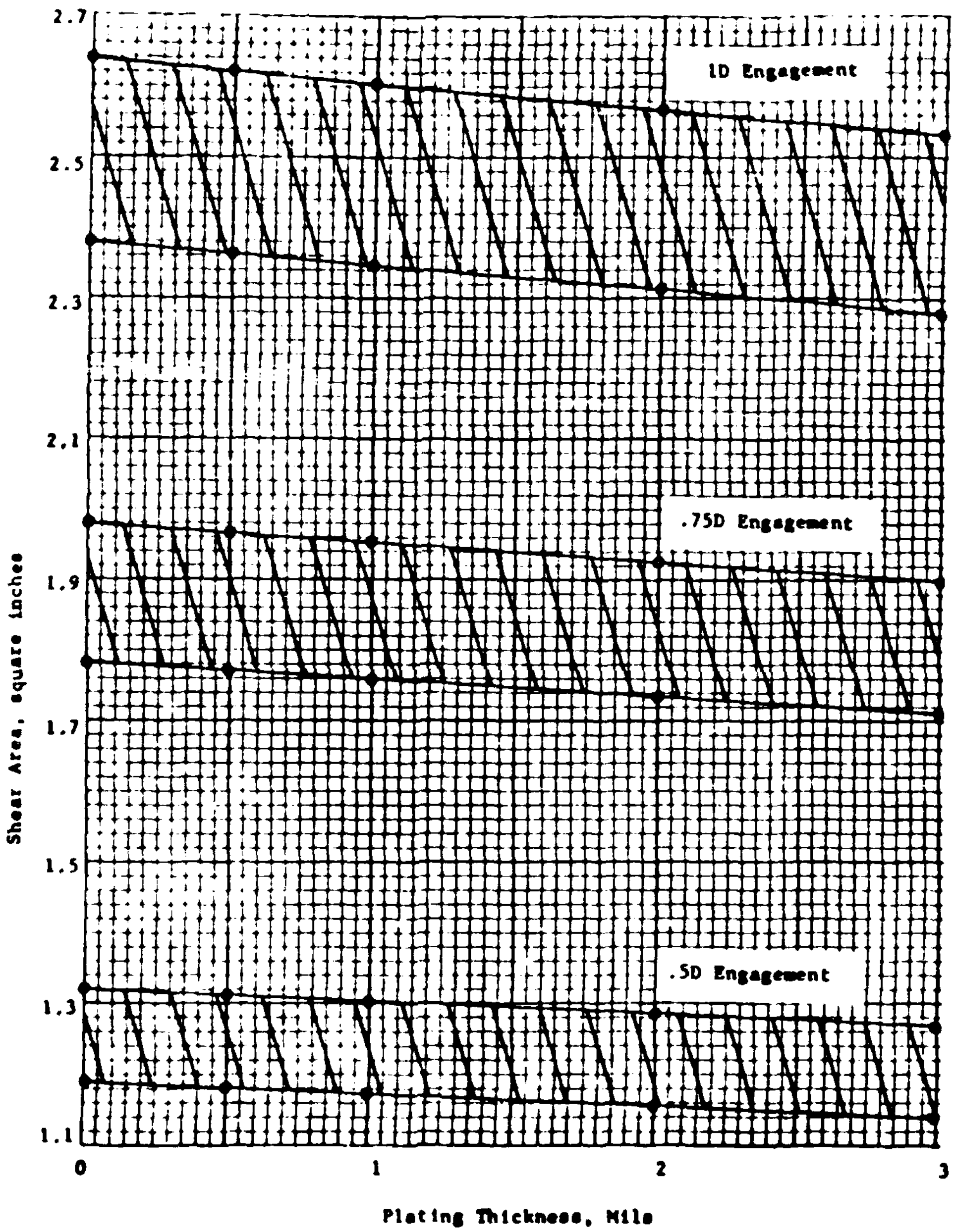


Figure 16. Effect of Plating Thickness and Thread Engagement on Shear Area of 1-8 Class 2 Internal Threaded Nut.

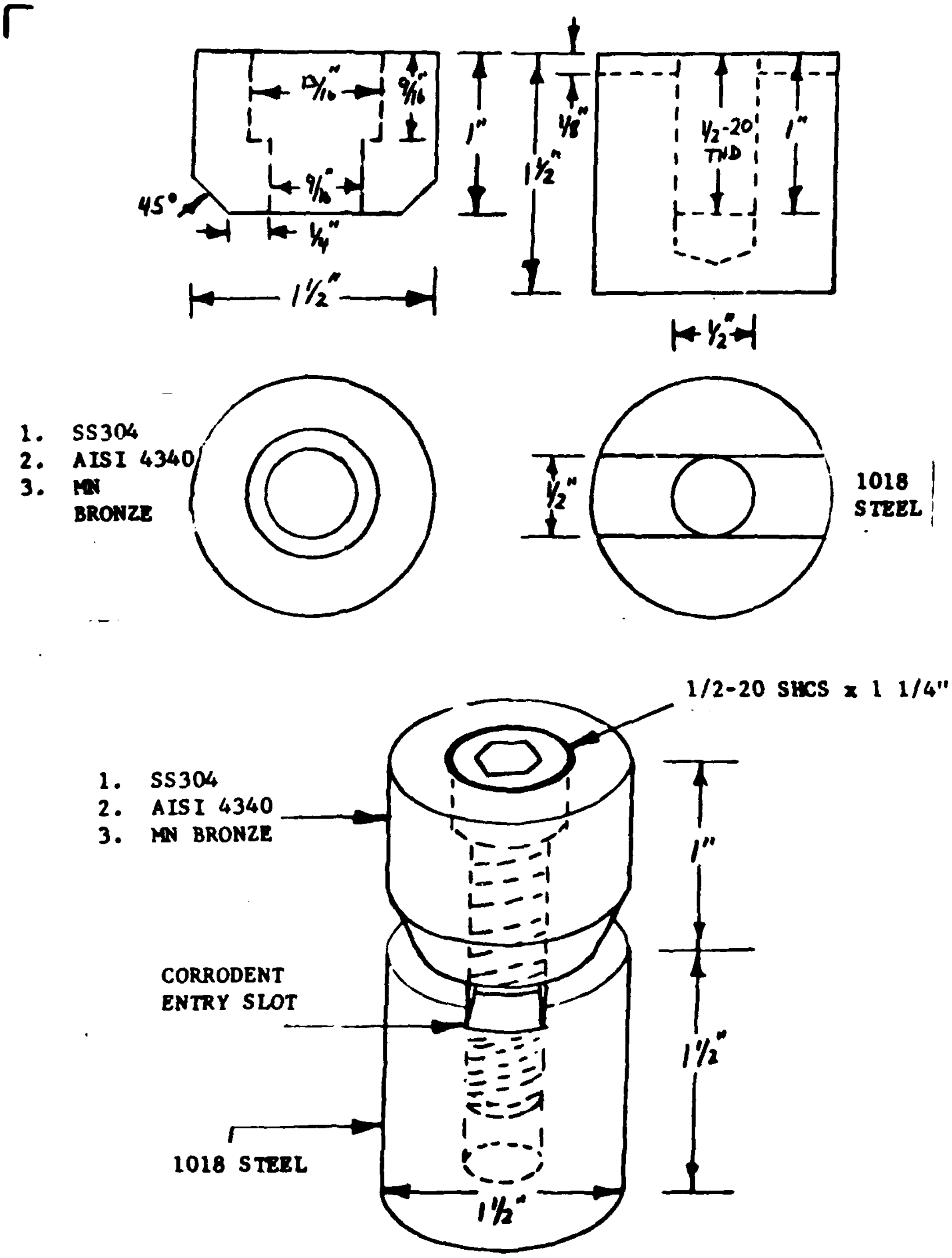


Figure 17. T-Bar, Bridle Track Screening Specimen

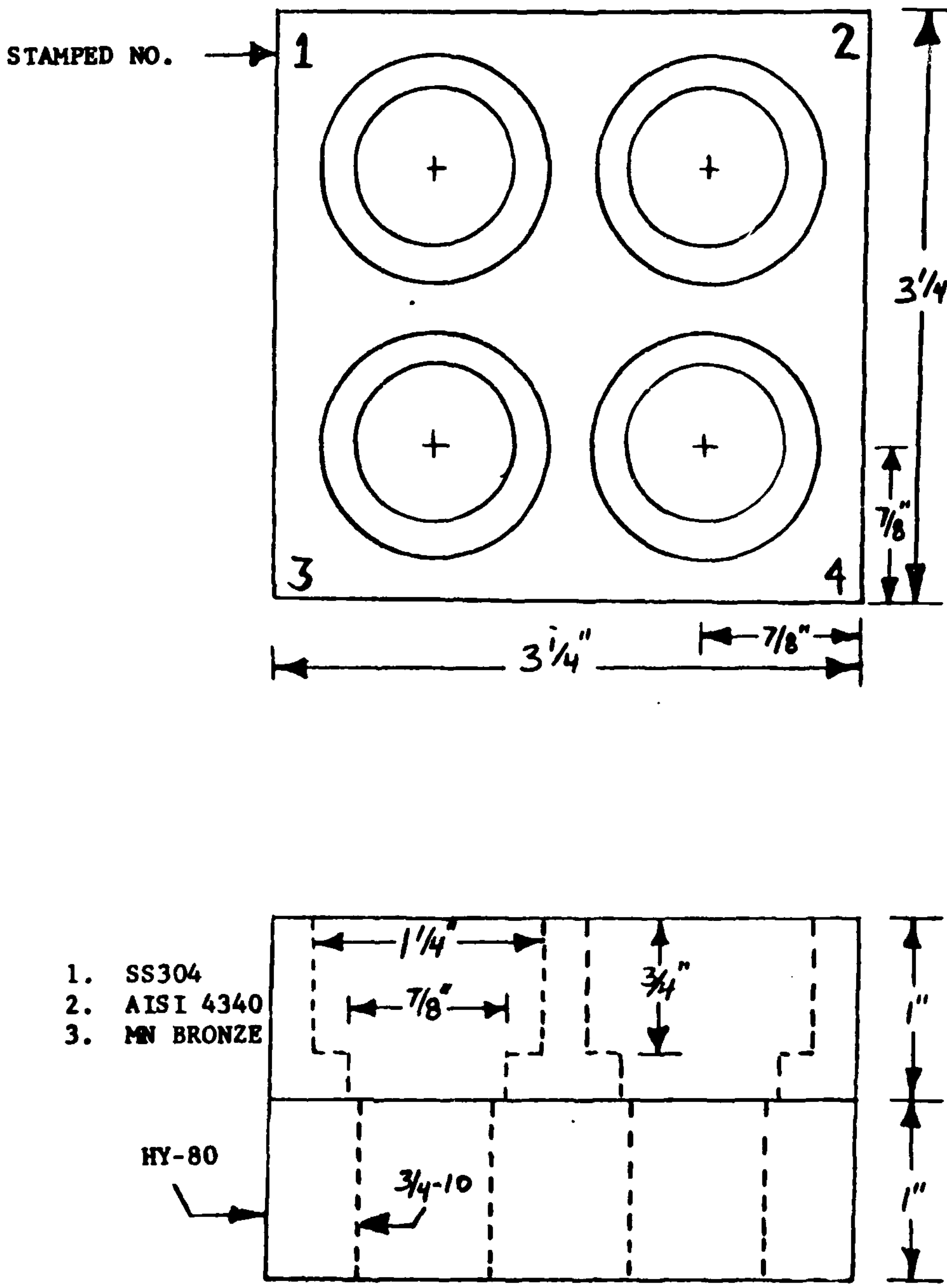


Figure 18. Low Temperature Long Term Specimen

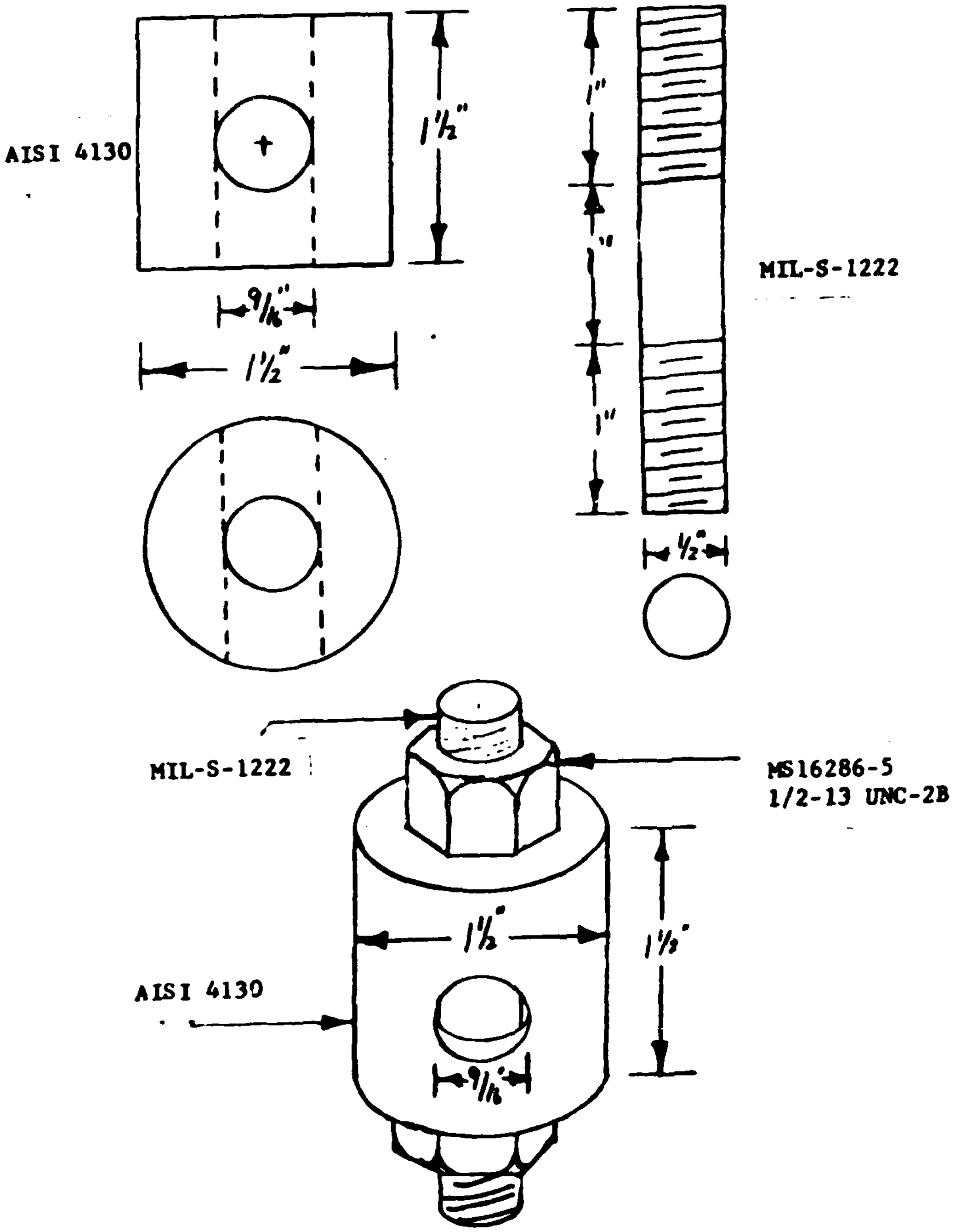
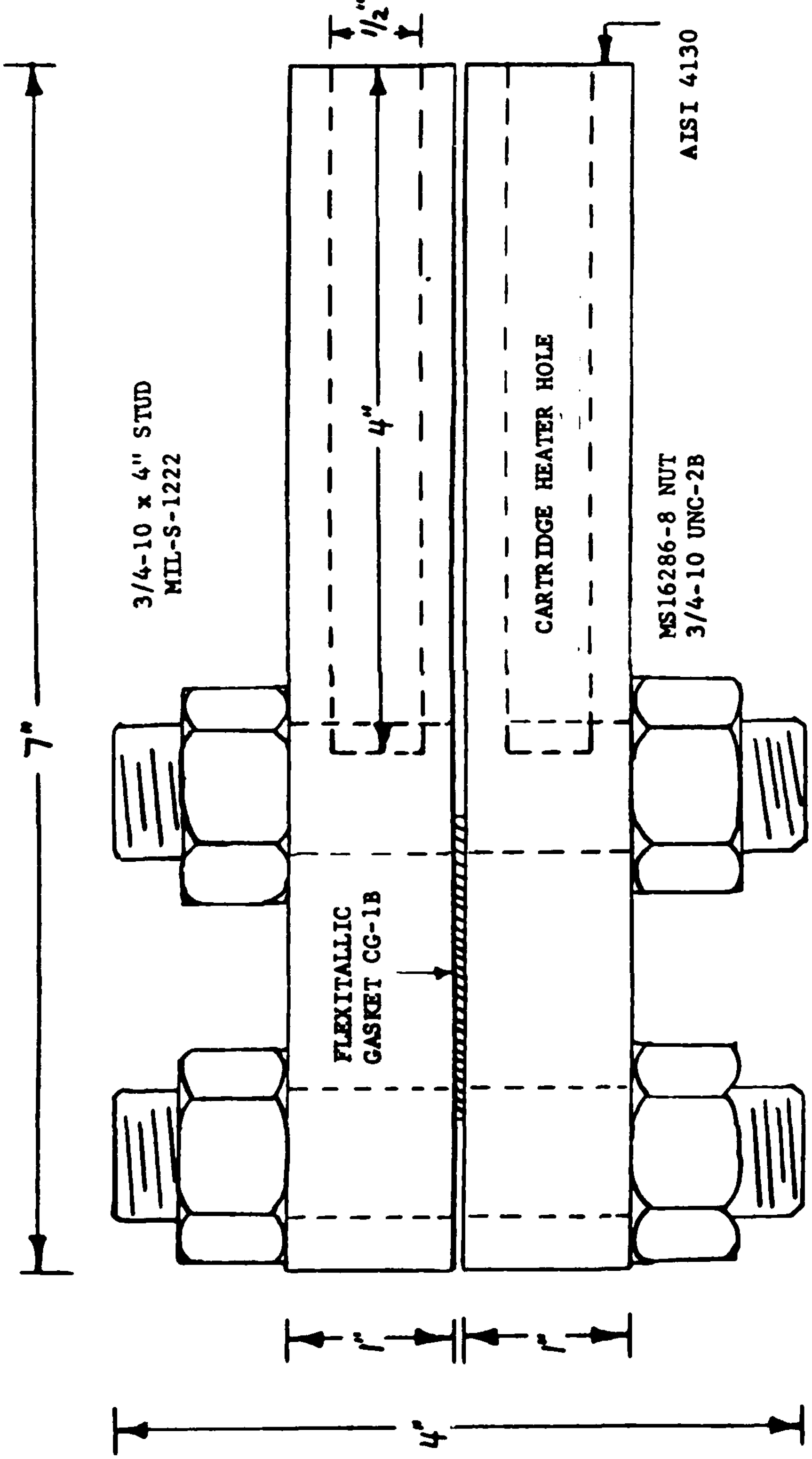


Figure 19. Pipe Flange Stud Screening Specimen



High Temperature Long Term Specimen - Side View

Figure 20.

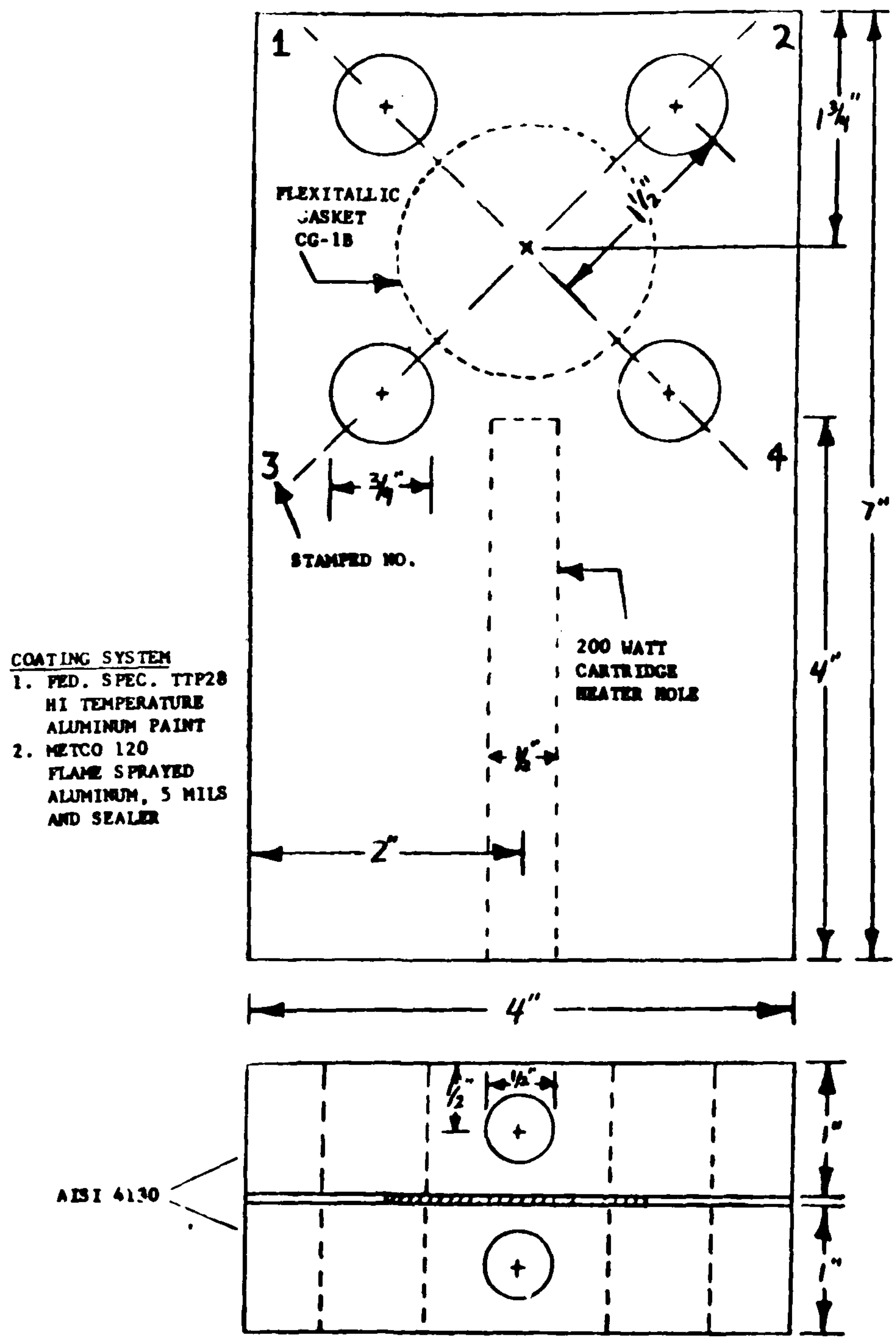
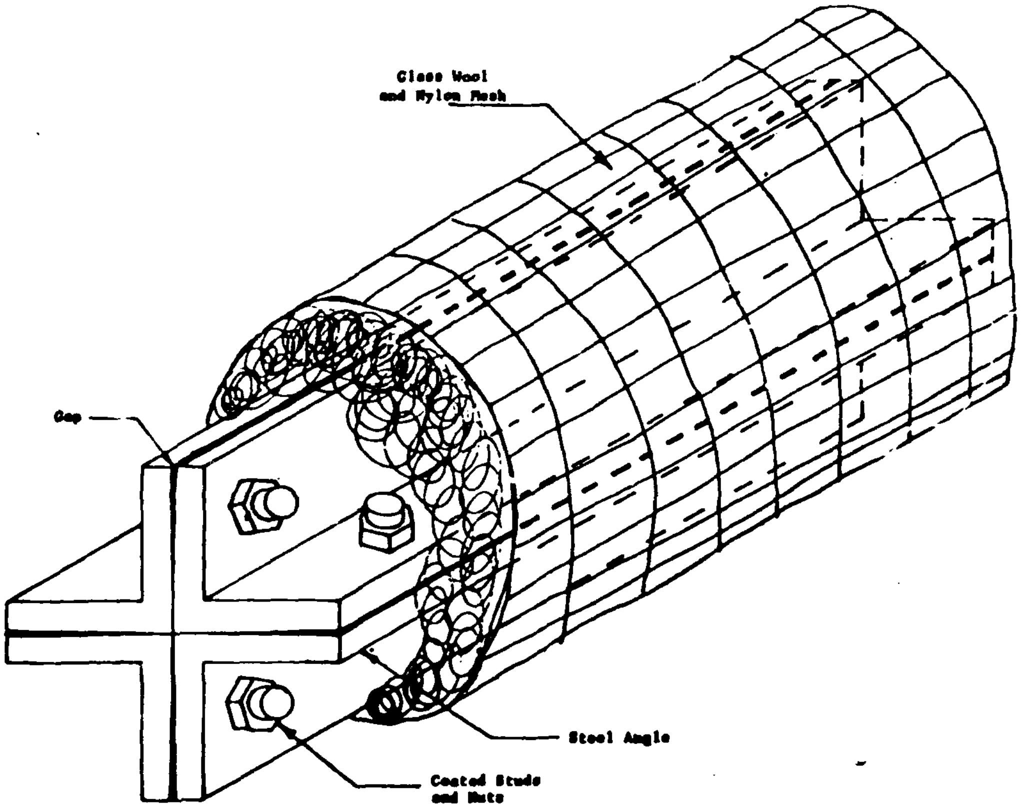


Figure 21. High Temperature Long Term Specimen - Top and End Views



<u>Figure 22.</u> Launch Valve Room Exposure Rack.

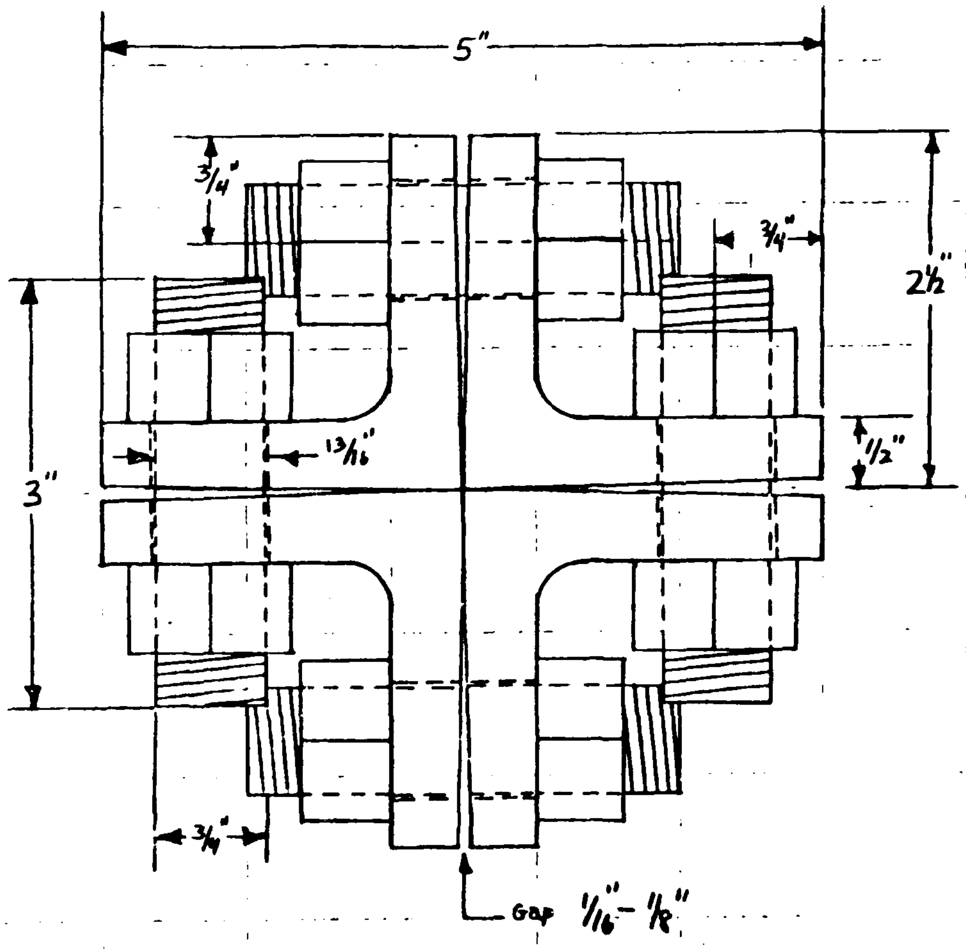
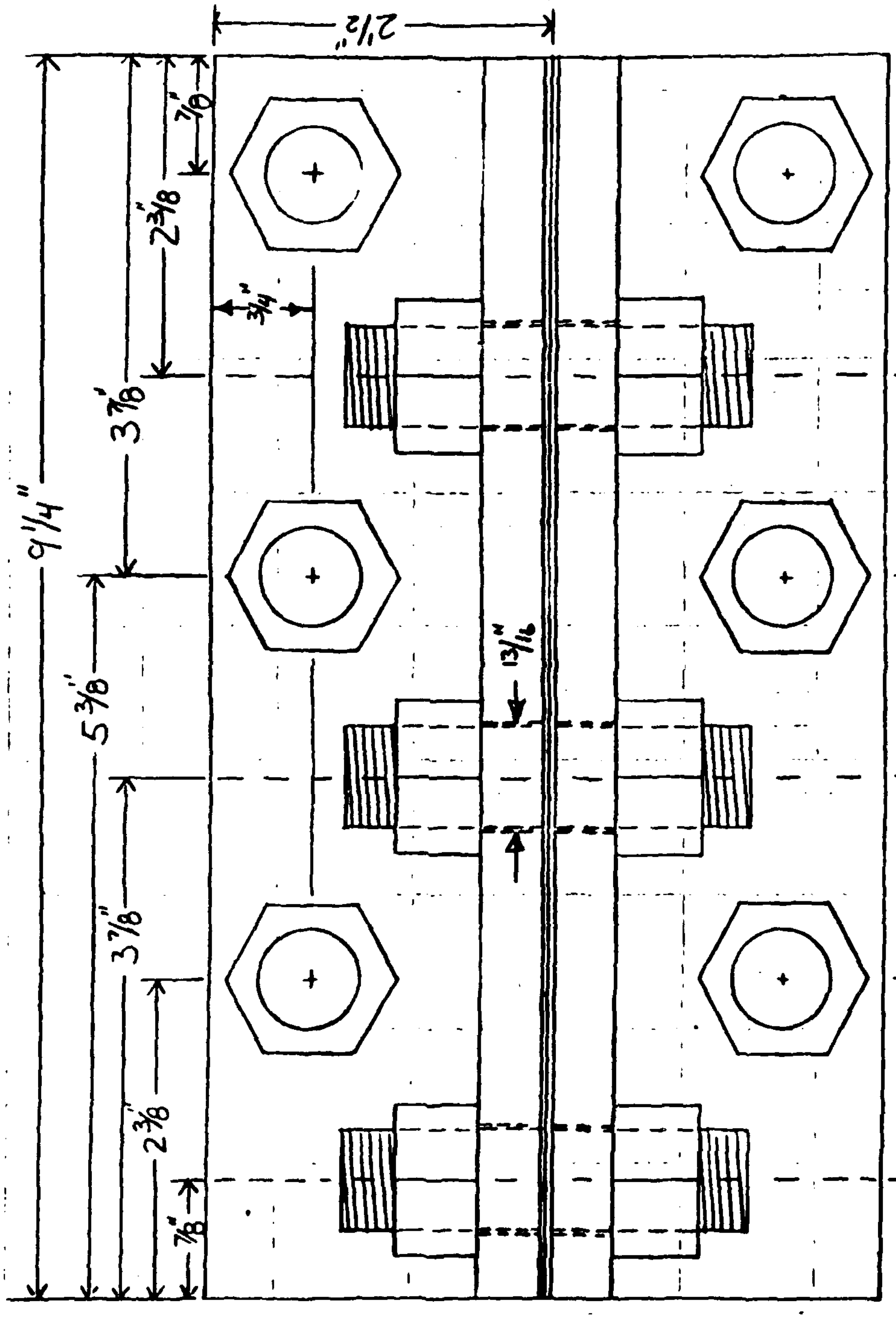


Figure 23. Carrier Exposure Rack - End View



Carrier Exposure Rack - Length View

Figure 24.

TABLE I

Summary of Calculations for Elevated Temperature Application

Bolt Material	E_B^R	E_B^T	α_B	F_B^T
Same as joint	30×10^6	26×10^6	7.7×10^{-6}	20,068 lb.
A-286	29×10^6	25×10^6	9.5×10^{-6}	1,301 lb.
PH13-8Mo	29.4×10^6	25×10^6	5.3×10^{-6}	44,604 lb.
MP35N	33.6×10^6	30.8×10^6	8.2×10^{-6}	14,507 lb.
Waspaloy	30.6×10^5	28.8×10^6	7.3×10^{-6}	26,379 lb.
Inconel 718	29.6×10^6	27.2×10^6	7.7×10^{-6}	21,182 lb.
17-4 PH	28.5×10^6	24.8×10^6	5.7×10^{-6}	40,724 lb.
MP159	35.3×10^6	31.5×10^6	7.9×10^{-6}	18,069 lb.

Note: The following values were fixed for this problem:

A_B = 0.7854 square inches

A_j = 228.55 square inches

d = 1 inch

D_1 = 13 inches

D_2 = 22 inches

E_j^R = 30×10^6 psi

E_j^T = 26×10^6 psi

F_T = 552,000 lb.

l_B = 4.5 inches

l_j = 4.5 inches

n = 24 bolts

ΔT = 570°F (650-80)

α_j = 7.7×10^{-6} in/in/°F

TABLE II

Dimensions for 1/2-13, Class 2, External (Bolt) Threads
All dimensions are inches

	Major Diameter		Pitch Diameter	
Plating Thickness	Max.	Min.	Max.	Min.
0	.5000	.4896	.4500	.4448
.0005	.4990	.4886	.4480	.4428
.0010	.4980	.4876	.4460	.4408
.0020	.4960	.4856	.4420	.4368
.0030	.4940	.4836	.4380	.4328

Internal thread is .4552/.4500 pitch diameter
.4290/.4167 minor diameter

TABLE III

Dimensions for 3/4-10, Class 2, External (Bolt) Threads
All dimensions are inches

	Major Diameter		Pitch Diameter	
Plating Thickness	Max.	Min.	Max.	Min.
0	.7500	.7372	.6850	.6786
.0005	.7490	.7362	.6830	.6766
.0010	.7480	.7352	.6810	.6746
.0020	.7460	.7332	.6770	.6706
.0030	.7440	.7312	.6730	.6666

Internal thread is .6914/.6850 pitch diameter
.6553/.6417 minor diameter

TABLE IV

Dimensions for 1-8, Class 2, External (Bolt) Threads
All dimensions are inches

	Major Diameter		Pitch Diameter	
Plating Thickness	Max.	Min.	Max.	Min.
0	1.000	.9848	.9188	.9112
.0005	.9990	.9838	.9168	.9092
.0010	.9980	.9828	.9148	.9072
.0020	.9960	.9808	.9108	.9032
.0030	.9940	.9788	.9068	.8992

Internal thread is .9264/.9188 pitch diameter
.8795/.8647 minor diameter

TABLE V

Effect of 1/2-13 Thread Dimensions on Shear Area

Diameter, in. External Major	P.D.	Shear Areas, square inches .5D-L.E. = .25 Int. A	Ext. A	.75D-L.E. = .375 Int. A	Ext. A	1D-L.E. = .500 Int. A	Ext. A
.5000	.4500	.328	.221	.492	.332	.656	.443
.4990	.4480	.325	.216	.487	.325	.649	.433
.4980	.4460	.321	.211	.482	.317	.642	.423
.4960	.4420	.314	.201	.471	.302	.628	.402
.4940	.4380	.307	.191	.460	.287	.613	.382
.4896	.4448	.291	.208	.437	.312	.583	.417
.4886	.4428	.288	.203	.432	.305	.576	.406
.4876	.4408	.284	.198	.426	.297	.569	.396
.4856	.4368	.277	.188	.416	.282	.555	.376
.4836	.4328	.271	.178	.406	.267	.542	.356

Notes:

1. P. D. means pitch diameter
2. L. E. means length of engagement
3. Internal thread at maximum condition, i.e. P.D. = .4552, minor = .4290

TABLE VI

Effect of 3/4-10 Thread Dimensions on Shear Area

Diameter, in. External		Shear Areas, square inches					
		.5D-L.E. = .375		.75D-L.E. = .563		1D-L.E. = .75	
Major	P.D.	Int. A	Ext. A	Int. A	Ext. A	Int. A	Ext. A
.7500	.6850	.740	.518	1.111	.778	1.481	1.036
.7490	.6830	.734	.509	1.102	.764	1.468	1.019
.7480	.6810	.728	.500	1.093	.751	1.456	1.001
.7460	.6770	.716	.483	1.075	.724	1.432	.965
.7440	.6730	.704	.465	1.057	.698	1.408	.929
.7372	.6786	.664	.489	.996	.735	1.327	.979
.7362	.6766	.658	.481	.987	.722	1.315	.961
.7352	.6746	.652	.472	.979	.708	1.303	.943
.7332	.6706	.640	.454	.961	.681	1.280	.908
.7312	.6666	.628	.436	.943	.655	1.257	.872

Notes:

1. P. D. means pitch diameter
2. L. E. means length of engagement
3. Internal thread at maximum condition, i.e. P.D. = .6914, minor = .6553

TABLE VII

Effect of 1-8 Thread Dimensions on Shear Area

Diameter, in. External		Shear Areas, square inches					
		.5D-L.E. = .5		.75D-L.E. = .75		1D-L.E. = 1.00	
Major	P.D.	Int. A	Ext. A	Int. A	Ext. A	Int. A	Ext. A
1.000	.9188	1.319	.941	1.978	1.412	2.638	1.882
.9990	.9168	1.310	.928	1.966	1.393	2.621	1.857
.9980	.9148	1.302	.916	1.953	1.374	2.604	1.831
.9960	.9108	1.285	.890	1.927	1.335	2.569	1.781
.9940	.9068	1.268	.865	1.902	1.297	2.536	1.730
.9848	.9112	1.190	.893	1.785	1.339	2.381	1.786
.9838	.9092	1.182	.880	1.773	1.320	2.364	1.760
.9828	.9072	1.174	.867	1.761	1.301	2.347	1.735
.9808	.9032	1.157	.842	1.735	1.263	2.314	1.684
.9788	.8992	1.141	.816	1.711	1.224	2.281	1.632

Notes:

1. P. D. means pitch diameter
2. L. E. means length of engagement
3. Internal thread at maximum condition, i.e. P.D. = .9264, minor = .8795

TABLE VIII

Maximum Percent Shear Area Loss as a Function of Plating Thickness

	Nut Plating Thickness Mils	Bolt Plating Thickness, Mils				
		0	.5	1	2	3
	0	0	8.2	10.5	15.0	19.5
	.5	12.2	20.4	22.7	27.2	31.7
1/2-13	1	13.4	21.6	23.9	28.4	32.9
Thread	2	15.4	23.6	25.9	30.4	34.9
	3	17.4	25.6	27.9	32.4	36.9
	0	0	7.2	9.0	12.4	15.9
	.5	11.1	18.2	20.0	23.4	26.9
3/4-10	1	12.0	19.1	20.9	24.3	27.8
Thread	2	13.5	20.7	22.5	25.9	29.4
	3	15.2	22.3	24.1	27.5	31.0
	0	0	6.5	7.8	10.5	13.3
	.5	10.4	16.9	18.2	20.9	23.7
1-8	1	11.0	17.5	18.8	21.5	24.3
Thread	2	12.2	18.7	20.0	22.7	25.5
	3	13.5	20.0	21.3	24.0	26.8

TABLE IX

Low Temperature Screening Program Coatings

No.	Coating
1.	Electroplated aluminum (0.5 mil)
2.	Flame sprayed aluminum (Not tested)
3.	Xenoclad aluminum (0.5 mil)
4.	Electroplated cyanide cadmium (0.5 mil) + Nylon 11
5.	Electroplated cyanide cadmium (0.2 - 0.4 min)
6.	Electroplated cyanide cadmium (0.5 mil min.)
7.	Electroplated cyanide cadmium (0.2 - 0.4 mil) + Teflon
8.	Electroplated cyanide cadmium (0.5 mil min.) + Polysulfide sealant
9.	Electroplated cyanide cadmium (0.5 mil min.) + soluble chromate
10.	Electroplated cyanide cadmium (0.2 mil) + electroplated cyanide zinc (0.3 mil)
11.	Coricone 800
12.	Diffused nickel-cadmium
13.	Electroplated sulfamate nickel (0.1 mil) + electroplated cyanide cadmium (0.4 mil)
14.	Electroplated sulfamate nickel (0.1 mil) + electroplated aluminum (0.4 mil)
15.	Electroplated sulfamate nickel (0.1 mil) + Xenoclad aluminum (0.4 mil)
16.	Electroplated sulfamate nickel (0.2 mil) + electroplated cyanide zinc (0.3 mil)
17.	Electroplated sulfamate nickel (0.5 mil)
18.	Electroplated sulfamate nickel (0.2 mil) + SermeTel W per AMS 2506
19.	SermeTel W per AMS 2506
20.	Electroplated sulfamate nickel (0.1 mil) + SermeTel 554
21.	Urethabond U-100 over U-107
22.	Electroplated cyanide zinc (0.2 - 0.4 mil)
23.	Electroplated cyanide zinc (0.2 - 0.4 mil) + Teflon
24.	Electroplated cyanide zinc (0.5 mil min.)
25.	Electroplated cyanide zinc (0.2 mil) + electroplated cyanide cadmium (0.3 mil)
26.	Mechanically plated tin-cadmium

TABLE X

Long-Term Low Temperature Coating Systems

No.	Coating System
1.	Electroplated cyanide cadmium (0.3 to 0.5 mil) + iridescent dichromate
2.	Electroplated cyanide cadmium (0.5 mil min.) + iridescent dichromate
3.	Electroplated cyanide cadmium (0.5 mil min.) + iridescent dichromate + PRC 1436G polysulfide sealant under head and on threads
4.	Electroplated cyanide cadmium (0.2 mil) + electroplated cyanide zinc (0.3 mil) + dichromate
5.	Electroless nickel (0.6 mil)
6.	Electroplated sulfamate nickel (0.3 to 0.5 mil)
7.	Diffused nickel-cadmium per AMS 2416
8.	SermeTel W per AMS 2506
9.	Electroplated cyanide zinc (0.3 to 0.5 mil) + dichromate
10.	Electroplated cyanide zinc (0.5 mil min.) + dichromate
11.	Electroplated cyanide zinc (0.5 mil min.) + dichromate + PRC-1436G polysulfide sealant underhead and on threads
12.	Electroplated cyanide zinc (0.2 mil) + electroplated cyanide cadmium (0.3 mil) + iridescent dichromate

TABLE XI

Long Term Low Temperature Conditions

Daily

1. Heat, 1 hour with cycle consisting of: hot air blast (400°F). duration 15 seconds; marine atmosphere 2 minutes, 45 seconds. Twenty cycles per hour.

2. Acidified seawater spray - 5 minutes (8% by wt. sulfurous acid).

3. Seawater immersion - 2 hours.

4. Marine atmosphere - 20 hours, 55 minutes.

Weekly

1. Using paint brush, all samples wet down with the following:

   a. lube oil (automotive grade)
   b. hydraulic (catapult) - MIL-H-22072A
   c. Aircraft cleaning solution - 50% MIL-C-43616, 50% MIL-C-25679

2. Scrub down with detergent mixture - 5% detergent, Type II, 95% JP-5. Simulates procedures described in NAVSHIPS Technical Manual, Chapter 9140, 22 June 66, "Cleaning Method A".

Continue cycle for 9 months.

TABLE XII

High Temperature Screening Program Coatings

No.	Coating
1.	Electroplated aluminum (0.5 mil)
2.	Electroplated sulfamate nickel (0.1 mil) + electroplated aluminum (0.4 mil)
3.	Diffused nickel-cadmium
4.	Electroplated sulfamate nickel (0.5 mil)
5.	Electroplated sulfamate nickel (0.1 mil) + SermeTel 554
6.	Electroplated sulfamate nickel (0.1 mil) + SermeTel W
7.	SermeTel W
8.	Inconel 718 studs and nuts

Note: A second test was run with all steel cylinders coated by NAEC with the Metco 120 system of wire sprayed aluminum

TABLE XIII

Long-Term High Temperature Coating Systems

No.	Coating System
1.	Bare studs and nuts
2.	Electroplated sulfamate nickel (.0004 inches thick)
3.	Electroplated sulfamate nickel (.0007 inches thick)
4.	Diffused nickel-cadmium per AMS 2416
5.	Electroless nickel (.0004 inches thick)
6.	Electroless nickel (.0007 inches thick)
7.	Electroplated sulfamate nickel (.0003 inches thick) and SermeTel W
8.	SermeTel W per AMS 2506
9.	SermeTel W (.0004 to .0007 inches thick) cured at 650°F - 15 min. and 1000°F - 1.5 hours
10.	Inconel 718 alloy studs and nuts

Note: All threaded surfaces coated with MIL-L-46010 (MR) dry film lubricant

TABLE XIV

Long Term High Temperature Conditions

1. Specimens mounted in test capsules simulating launch valve insulation procedures.

2. Monday - inject 500 ml. solution into each specimen. Solution contains: 85% seawater solution of 2% salinity (deionized water diluted), 5% hydraulic fluid (MIL-H-22072A), 5% aircraft cleaning solution (50% MIL-C-43616, 50% MIL-C-25679), 5% deck washdown solution 5% detergent Type II, 95% JP-5).

3. Monday Noon: Turn on heaters, set to approx. 150°F.

4. Monday 5 P.M.: Increase temperature to approx. 300°F.

5. Tuesday 4 P.M.: Increase temperature to approx. 450°F.

6. Wednesday 4 P.M.: Increase temperature to approx. 600°F.

7. Thursday 4 P.M.: Increase temperature to approx. 700°F.

8. Friday 4 P.M.: Turn off heaters until Monday.

9. Continue cycle for 9 months.

TABLE XV

Exposure Rack Coating Systems

1. Bare

2. Diffused Nickel-Cadmium

3. Electroplated Sulfamate Nickel (0.7 mil)

4. Electroless Nickel (0.4 mil)

5. Electroplated Sulfamate Nickel (0.4 mil)

6. Inconel 718

Note: All threaded areas coated with inhibited dry film lubricant Sandstrom 9A

TABLE XVI

Metal Sprayed Coatings

Code	Description
A	Aluminum (wire spray)
AM*	Aluminum and molybdenum wire spray - simultaneously sprayed
AMP*	Aluminum powder and Multiphase MP35N powder 1:1 mixture
AT	Aluminum powder and titanium powder 1:1 mixture
MP	Multiphase MP35N (powder)
NA	Nickel Aluminide base coat and aluminum top coat
T	Titanium
Z	Zinc (wire spray)
ZA	Zinc and aluminum wire spray - simultaneously sprayed

Processing Instructions:

1. Coat 5 each of the 1/2 inch coarse and fine fasteners with the coatings above to a total thickness not to exceed .002 inches. Two each (coarse and fine thread) of items marked * are to be heated to 1000°F for one hour subsequent to coating and identified by coating lower 1/4 inch of threaded area with zinc chromate primer.

2. Coat 5 each of the 1/2 inch coarse and fine fasteners with the coatings above to a minimum thickness of .003 inches and a maximum of .004 inches.

3. Coat four 1 inch dia. bolts with above coatings to max. thickness of .002 inches. Heat treat and identify 2 each of the items marked with *.

4. Coat four 1 inch dia. bolts with above coatings to min. thickness of .002 inches and max. thickness of .003 inches.

5. Grit blast all over to white metal before coating.

TABLE XVII

Low Temperature Screening Test Results

Coating		Upper Bushing Material Steel	Stainless Steel	Manganese Bronze
No. 1 Electroplated Aluminum		Plating visible lower half inch of threads. Recess rusty. Area near slot rusty.	Plating visible lower half inch of threads. Recess rusty. Area near slot rusty.	Plating visible lower half inch of threads. Recess rusty. Area near slot rusty.
		Rusty I. D. and bearing face except for fillet bearing area.	No attack.	No attack.
		Threads rusty.	Threads slightly rusty.	Threads rusty.
No. 2 Flame Spray Aluminum		Not tested.	Not tested.	Not tested.
		Not tested.	Not tested.	Not tested.
		Not tested.	Not tested.	Not tested.
No. 3 Thermal Decomposition Aluminum		Plating visible lower half inch of threads. Remainder of area rusty.	Plating visible lower half inch of threads. Remainder of area rusty.	Plating visible lower half inch of threads. Remainder of area rusty.
		Inner surface totally rusty.	No attack.	No attack.
		Threads rusty.	Threads slightly rusty.	Threads slightly rusty.
No. 4 Cadmium + Nylon		Rusty in recess under head and area near slot. Nylon lifting.	Rusty in recess under head and lower threads. Nylon lifting.	Rusty head O.D. and recess. Nylon lifting.
		Rusty I.D. and bearing face except for fillet bearing area.	No attack.	No attack.
		Threads clean.	Threads clean.	Threads clean.

TABLE XVII - (Continued)

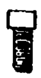
Coating		Upper Bushing Material: Steel	Stainless Steel	Manganese Bronze
No. 5 Cadmium, 0.2 - 0.4 mil		Plating visible lower half inch of threads. Very slightly rusty on recess side. Recess edge attacked.	Plating visible lower half inch of threads. Rust evident in slot area, under head and in recess.	Plating visible lower half inch, slight rusting elsewhere.
		Inner surface totally rusty.	No attack.	No attack.
		Threads very slightly rusty.	Threads extremely rusty.	Threads extremely rusty.
No. 6 Cadmium, 0.5 mil min.		Plating visible lower half inch of threads. Rusty elsewhere, but not heavy.	Plating visible lower half inch of threads, below fillet, and recess bottom.	Plating visible lower half inch of threads and fillet. Recess bottom rusty, light rust on head.
		Inner surface totally rusty.	No attack.	No attack.
		Threads appear dirty but not rusty.	Threads appear dirty but not rusty.	Threads rusty.
No. 7 Cadmium + Teflon		Teflon flaking off, no cadmium evident beneath except on lower half inch of threads. Rusting light.	Teflon not evident except some in fillet and on lower half inch of threads. Slightly rusty elsewhere.	Teflon evident only lower half inch of threads. Slightly rusty elsewhere.
		Inner surface rusty except for fillet area.	No attack.	No attack.
		Threads clean.	Threads rusty.	Threads rusted extensively.
No. 8 Cadmium + Sealant		Plating visible lower half inch of threads. Rusty elsewhere, not heavy.	Plating visible lower half inch of threads. Rusty elsewhere, not heavy.	Plating visible lower half inch of threads and below fillet. Scale in recess.
		Inner surface rusty except for bearing face and below fillet.	No attack.	No attack.
		Threads exceptionally clean.	Threads rust covered but not attacked.	Threads rusty.

TABLE XVII - (Continued)

Coating		Upper Bushing Material: Steel	Stainless Steel	Manganese Bronze
No. 9 Cadmium + Soluble Chromate		Not tested.	Slot area rusty, coating scraped off lower threads leaving cadmium intact.	Plating intact lower half inch of threads. Rusty recess, top of head and slot area.
		Not tested.	No attack.	No attack.
		Not tested.	Threads rusty.	Threads very rusty.
No. 10 Cadmium + zinc		Plating visible lower half inch of threads and some underhead. Recess rusty.	Plating intact on threads. Recess rusty.	Plating depleted in slot area.
		Inner surface rusty except for fillet area.	No attack.	No attack.
		Threads clean.	White deposit on threads.	White deposit on threads.
No. 11 Coricone 800		Coating stripped off threads 5% area, rusty, pooling on head and under head.	5% coating stripped from threads, severe crevice attack on head and around recess.	1% coating stripped from threads, stripped under head where crevice attack observed. Recess also crevice attacked.
		Heavy rust on inner surface.	No attack.	No attack.
		Threads rusty.	Threads rusty.	Threads rusty.
No. 12 Diffused Nickel-Cadmium		Light rust almost non-existent.	Heavy rust breach bottom and near slot. Recess edge attacked.	Light rust only in slot area and recess.
		Internal area rusty.	No attack.	No attack.
		Threads slightly rusty.	Threads rusty.	Threads lightly rusted.
No. 13 Nickel + Cadmium		Plating intact lower half inch of threads. Slot area slightly rusty. Rusty under head and in recess.	Plating intact lower half inch of threads. Fillet area slightly rusty. Recess rusty.	Plating intact lower half inch of threads, rusty slot area, recess and top of head attacked.
		Inner surface rusty except for fillet area.	No attack.	No attack.
		Threads slightly rusty.	Threads slightly rusty.	Threads slightly rusty.

TABLE XVII - (Continued)

Coating		Upper Bushing Material Steel	 Stainless Steel	 Manganese Bronze
No. 14 Nickel + Electroplated Aluminum		Coating intact all over. Slightly rusty in recess and on threads.	Coating intact, broach rusty.	Coating stained in slot area, broach attacked slightly on edge, more on bottom.
		Inner surface rusty.	Slight crevice attack.	No attack.
		Threads slightly rusty.	Threads slightly rusty.	Threads slightly rusty.
No. 15 Nickel + Thermal Decomposition Aluminum		Nickel intact all over. Rust stains, but no attack.	Crevice attack under head edge, broach bottom and edge.	Coating lower half inch of threads, O.K. Rusty slot area. Attack head edge, recess edge, broach bottom.
		Inner surface rusty.	No attack.	No attack.
		Threads rusty.	Threads very rusty.	Threads rusty.
No. 16 Nickel + Zinc		Coating visible lower half inch of threads. Rusty slot, under head and recess.	Coating visible lower half inch of threads. Rusty slot and recess.	Rusty slot area, recess area.
		Inner surface rusty.	No attack.	No attack.
		Threads slightly rusty.	Threads slightly rusty.	Threads rusty.
No. 17 Nickel, 0.5 mil min		Rust stains. Neglible attack.	Slight attack slot area, heavy attack recess bottom.	Insignificant attack except for recess bottom.
		Inner surface completely rusty.	Slight crevice attack.	No attack.
		Threads rusty.	Threads rusty.	Threads rusty.
No. 18 Nickel + SermeTel W		Rusty recess and slot area.	Rusty recess and slot area.	Rusty recess and slot area, attacked under head and edge of recess.
		Inner surface rusty except for fillet area.	No attack.	No attack.
		Threads rusty,	Threads slightly rusty.	Threads rusty.

TABLE XVII - (Continued)

Coating		Upper Bushing Material Steel	Stainless Steel	Manganese Bronze
No. 19 SermeTel W		Coating intact lower half inch of threads. Peeling very slightly. Rusting upper half inch of threads. Recess side slightly rusty. Chipping on head.	Thread coating intact. Attack under head with rust bleeding. Recess side and edge attacked.	Thread coating intact. Attack under head, recess side and edge.
		Rusty inner surface except for fillet area.	No attack.	No attack.
		Threads very slightly rusty.	Threads slightly rusty.	Threads rusty.
No. 20 SermeTel 554		Rust stains on threads, recess rusty.	Threads rust stained, attack under head, recess edge, and bottom.	Coating O.K. lower half inch, recess edge and bottom attacked.
		Rusty inner surface except for fillet area.	No attack.	No attack.
		Threads slightly rusty.	Threads rusty.	Threads clean.
No. 21 Urethabond		Rusty slot, fillet, recess.	Coating intact on 95% of threaded area. Lifting on head. Recess rusty.	Coating intact on thread area except for slot area. Recess edge and bottom attacked.
		Inner surface completely rusty.	No attack.	No attack.
		Threads rusty.	Thread very slightly rusty.	Threads slightly rusty.
No. 22 Zinc, 0.2 - 0.4 mil		Rusty slot and recess areas.	Rusty slot and recess areas.	Rusty slot and recess areas.
		Inner surface completely rusted.	No attack.	No attack.
		Threads clean.	Threads clean.	Threads slightly rusty.

TABLE XVII - (Continued)

Coating		Steel	Upper Bushing Material Stainless Steel	Manganese Bronze
No. 23 Zinc + Teflon		Rusty slot and recess. Peeling on head.	Rusty slot and recess. Peeling on head.	Rusty slot and recess. Peeling on head.
		Rusty inner surface except for fillet area.	No attack.	No attack.
		Threads slightly rusty.	Threads very rusty.	Threads slightly rusty.
No. 24 Zinc, 0.5 mil min.		Plating visible lower half inch of threads and fillet area. Light rust on threads and heavier scale in recess.	Plating visible lower half inch of threads and fillet area. Rust in slot area and heavy in recess bottom.	Plating visible lower half inch of threads and fillet area. Rust in slot area and heavy in recess bottom.
		Rusty inner surface except for fillet area.	No attack.	No attack.
		Threads lightly rusted in spots.	Threads very clean.	Threads rusty.
No. 25 Zinc + Cadmium		Plating intact lower half inch of threads. Rusty slot area, recess, fillet.	Plating intact lower half inch of threads. Rusty slot area, recess, fillet slightly rusty.	Plating intact lower half inch of threads. Rusty slot area, recess fillet not rusty.
		Inner surface rusty except for fillet area.	No attack.	No attack.
		Threads clean.	Threads clean.	Threads rusty.
No. 26 Tin-Cadmium		Plating intact lower half inch of threads. Rusty slot area, recess, fillet.	Plating intact lower half inch of threads. Rusty slot area, recess, fillet.	Plating intact lower half inch of threads. Rusty area, recess, fillet.
		Inner surface completely rusty.	No attack.	No attack.
		Threads rusty.	Threads rusty.	Threads rusty.

TABLE XVIII

Low Temperature Long Term Salt Spray Test Results

Coating		Upper Plate Material: Steel HY80	Stainless Steel 304	Manganese Bronze
No. 1 Cadmium 0.3 to 0.5 mil + chromate		Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.
		Rusty.	Rust stained.	Rust stained.
		Rusty.	Rusty.	Rusty.
No. 2 Cadmium 0.5 mil min. + chromate		Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.
		Rusty.	Rust stained.	Rust stained.
		Slightly rusty.	Slightly rusty.	Slightly rusty.
No. 3 Cadmium 0.5 mil min. + chromate + polysulfide sealant		Head and drive rusty. Underhead clean. Threads clean.	Head and drive rusty. Underhead clean. Threads clean.	Head and drive rusty. Underhead clean.
		Rusty.	Clean.	Clean.
		Very slightly rusty.	Clean.	Very slightly rusty.
No. 4 Cadmium 0.2 mil +Zinc 0.3 mil + chromate		Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive slightly rusty. Underhead slightly rusty. White corrosion products on threads.	Head and dr[illegible] rusty. Underhead rusty. White corrosion products on threads.
		Rusty.	White corrosion products.	Rust stains and white corrosion products.
		White corrosion products on threads.	White corrosion products.	White corrosion products and slightly rusty.
No. 5 Nickel, electroless 0.6 mil		Head and drive very slightly attacked. Underhead clean. Threads very slightly attacked.	Head and drive pitted. Underhead attacked. Threads clean.	Head and drive severely attacked. Underhead clean. Threads clean.
		Rusty.	Rust stained.	Rust stained.
		Rusty.	Rusty.	Rusty.

TABLE XVIII - (Continued)

Low Temperature Long Term Salt Spray Test Results

Upper Plate Material

Coating	Steel HY80	Stainless Steel 304	Manganese Bronze
No. 6 Nickel, electroplated 0.3 to 0.5 mil	Drive bottom pitted. Underhead clean. Threads clean.	Head and drive slightly attacked. Fillet attacked. Threads clean.	Head and drive severely attacked. Underhead clean. Threads clean.
	Rusty.	Rust stained.	Rust stained.
	Rusty.	Rusty.	Rusty.
No. 7 Nickel-cadmium, diffused	Head and drive clean. Underhead clean. Threads clean.	Head clean, drive attacked. Underhead clean. Threads clean.	Head and drive attacked. Underhead clean. Threads clean.
	Rusty.	Rust stained.	Rust stained.
	Rusty.	Rusty.	Rusty.
No. 8 SermeTel W 0.4 to 0.7 mil	Head clean, drive attacked slightly. Underhead clean. Threads clean.	Head and drive attacked. Underhead clean. Threads clean.	Head and drive attacked. Underhead clean. Threads attacked.
	Rusty.	Rust stained.	Rust stained.
	Rusty.	Rusty.	Rusty.
No. 9 Zinc 0.3 to 0.5 mil + chromate	Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. White corrosion products underhead and on threads.
	Rusty.	Rust stained.	Rust stained.
	White corrosion products.	White corrosion products.	White corrosion products.
No. 10 Zinc 0.5 mil min. + chromate	Head and drive rusty. White corrosion products underhead and on threads.	Head and drive rusty. White corrosion products underhead and on threads.	Head and drive rusty. White corrosion products underhead and on threads.
	Rusty.	Rust stained.	Rust stained.
	White corrosion products.	White corrosion products.	[illegible]te corrosion [illegible]oducts.

TABLE XVIII - (Continued)

Low Temperature Long Term Salt Spray Test Results

Coating		Upper Plate Material: Steel HY80	Stainless Steel 304	Manganese Bronze
No. [illegible] Zinc 0.5 mil min. + chromate + polysulfide sealant		Head and drive rusty. Underhead rusty. Threads clean.	Head and drive rusty. Underhead clean. Threads clean.	Head and drive rusty. Underhead clean. Threads clean.
		Rusty.	Rust stained.	Rust stained.
		Threads clean.	Threads clean.	Threads clean.
No. 12 Zinc 0.2 mil + cadmium 0.3 mil + chromate		Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.	Head and drive rusty. Underhead rusty. White corrosion products on threads.
		Rusty.	Rust stained.	Rust stained.
		White corrosion products.	White corrosion products.	White corrosion products.

TABLE XIX

Long Term Low Temperature Test Results - 2 1/2 Months

	Upper Plate Material		
	Steel HY80	Stainless Steel 304	Manganese Bronze
No. 1 Cadmium 0.3 to 0.5 mil + chromate	Gray colored bolt heads, good protection around heads due to sacrificial action.	Gray colored bolt heads.	Gray colored bolt heads with some rust spots.
No. 2 Cadmium 0.5 mil min. + chromate	Gray colored bolt heads, good protection around heads due to sacrificial action.	White corrosion products on head.	Rusty around bolt head edge.
No. 3 Cadmium 0.5 mil min. + chromate + polysulfide sealant	Gray colored bolt heads, good protection around heads due to sacrificial action	White corrosion products on head.	Rusty around bolt head edge.
No. 4 Cadmium 0.2 mil min. + zinc 0.3 mil + chromate	Gray colored bolt heads. Lightly rusting.	Gray colored bolt head - clean appearance.	Head rusty on top, in recess and around edge.
No. 5 Nickel electroless 0.6 mil	Head stained with rust, recess lightly rusted, no sacrificial protection of steel block.	Rust around head and in recess.	Rusty all over.
No. 6 Nickel electroplated 0.3 to 0.5 mil	Head stained with rust.	Rust stained on head and in recess.	Rusty around head and in recess.
No. 7 Nickel-cadmium, diffused	Rust stained around head and in recess. Bolt black colored.	Rust stained around head and in recess. Bolt black colored.	Rust stained around head and in recess. Bolt black colored.
No. 8 SermeTel W 0.4 to 0.7 mil	Rust speckled all over head. No sacrificial protection of steel block.	Rusty recess bottom.	Rusty all over.
No. 9 Zinc 0.3 to 0.5 mil + chromate	Some white corrosion product in recess. Better throwing power protection around bolt than cadmium.	White corrosion products on head and in recess.	Rusty recess bottom.
No. 10 Zinc 0.5 mil min. + chromate	White corrosion products in recess. Better throwing power protection around bolt than cadmium.	White corrosion products on head and in recess.	Rusty recess bottom.
No. 11 Zinc 0.5 mil min. + chromate + polysulfide sealant	Some white corrosion product in recess. Better throwing power protection around bolt than cadmium.	White corrosion products on head and in recess.	Rusty recess bottom.
No. 12 Zinc 0.2 mil + cadmium 0.3 mil + chromate	Gold layer peeling leaving black surface below. Throwing power protection not so good as pure zinc.	Very good original gold appearance with small black black spots in recess.	Almost all black appearance except for recess.

TABLE XX

Long Term Low Temperature Test Results - 4 1/2 months

	Upper Plate Material		
	Steel HY80	Stainless Steel 304	Manganese Bronze
No. 1 Cadmium 0.3 to 0.5 mil + chromate	Head and drive rusty, Some plating remaining on threads. Rusty under head. Threaded hole clean, counterbore slightly rusty.	Recess rusty, plating present on threads, counterbore clean.	Head and recess rusty, underhead black. Some plating still on threads. Threaded hole clean, counterbore black.
No. 2 Cadmium 0.5 mil min. + chromate	Head and drive rusty. Some plating remaining on threads. Threaded hole clean, counterbore rusty.	Recess rusty, plating present on threads. Counterbore and threaded hole clean.	Head and drive rusty. Underhead black. Some plating remaining on threads. Counterbore black, threaded hole clean.
No. 3 Cadmium 0.5 mil min. + chromate + polysulfide sealant	Recess very slightly rusty, head gray, sealant intact under head, threads clean. Counterbore clean, threaded hole clean.	Slightly rusty recess, gray head, sealant intact under head, threads clean. Counterbore clean, threaded hole clean.	Rusty drive and head, black under head, threads clean. Black counterbore, Threaded hole clean.
No. 4 Cadmium 0.2 mil min. + zinc 0.3 mil + chromate	Recess slightly rusty, head gray. Slight white corrosion products on threads. Underhead slightly corroded. Counterbore and threaded hole clean with some white corrosion products.	Recess and head gray. Some white corrosion products on threads. Counterbore and threaded hole clean with some white corrosion products on threads.	Head and recess rusty. Underhead rusty. White corrosion products on threads. Counterbore rusty. Threaded hole clean with some white corrosion products.
No. 5 Nickel electroless 0.6 mil	Head and recess rusty. Corrosion products on threads. Counterbore rusty. Threaded hole slightly rusty.	Head and recess rusty Black products on threads. Counterbore and threaded hole black.	Head and recess rusty. Black products on threads, counterbore and in threaded hole.
No. 6 Nickel electroplated 0.3 to 0.5 mil	Recess rusty and also around head. Threads black, counterbore rusty. Threaded hole slightly rusty.	Recess and around head rusty. Threads black, counterbore rusty, threaded hole black.	Recess and around head rusty. Threads slightly black. Counterbore rusty, threaded hole slightly rusty.
No. 7 Nickel-cadmium, diffused	Head and drive rusty, threads black, counterbore and threaded hole black.	Recess rusty, head and threads black. Counterbore clean, threaded hole black.	Head and threads rusty, threads black. Counterbore rusty, threaded hole black.
No. 8 SermeTel W 0.4 to 0.7 mil	Recess slightly rusty, also around head. Threads black, counterbore and threaded hole rusty and black.	Recess and around head and threads black. Counterbore clean, threaded hole black.	Head and recess rusty, threads black. Counterbore rusty, threaded hole black.
No. 9 Zinc 0.3 to 0.5 mil + chromate	Head and recess rusty. Some plating remaining. Threads dark gray. Counterbore rusty, threaded hole clean.	Recess and around head rusty, threads black. Counterbore rust stained. Threaded hole light gray with white corrosion products.	Recess and head rusty. Threads slightly rusty with white corrosion products. Counterbore rust stained and threaded hole light gray with white corrosion products.
No. 10 Zinc 0.5 mil min + chromate	Head and recess rusty, white corrosion products on threads. Counterbore slightly rusty. Threaded hole clean but white.	Recess and around head rusty. White corrosion products on threads. Counterbore rust stained and threaded hole white.	Head and recess rusty. Threads slightly rusty with white and black corrosion products present. Counterbore stained red but threaded hole white.
No. 11 Zinc 0.5 mil min + chromate + polysulfide sealant	Head and recess rusty Underhead and threads clean. Counterbore rusty. Threaded hole clean.	Recess and around head rusty. Underhead and threads clean, counterbore stained, threaded hole clean.	Recess and head rusty. Threads clean, counterbore rusty, threaded hole clean.
No. 12 Zinc 0.2 mil + cadmium 0.3 mil + chromate	Recess and around head slightly discolored. Threads have plenty of plating present. Counterbore clean, threaded hole clean but slightly gray.	Recess and around head slightly discolored. Threads clean, plating peeling on threads. Counterbore and threaded hole clean, latter gray.	Head and recess rusty. Threads clean but stained. Counterbore rust stained, threaded hole clean but gray.

TABLE XXI

Long Term Low Temperature Test Results - 7 Months

	Upper Plate Material		
Coating	Steel HY80	Stainless Steel 304	Manganese Bronze
No. 1 Cadmium 0.3 to 0.5 mil + chromate	Head rusty and flaking, recess rusty, threads black, point rusty. Threaded hole black but not rusty, counterbore rusty.	Head and recess rusty, threads black, point rusty. Threaded hole gray but clean, counterbore rust stained.	Head flaking and recess rusty, threads black except under head, point rusty. Threaded hole gray but clean, counterbore rust stained.
No. 2 Cadmium 0.5 mil min + chromate	Head rusty and flaking, recess rusty, threads black, point rusty. Threaded hole black but not rusty, counterbore rusty.	Head and recess rusty, threads black, Threaded hole gray but clean, counterbore rust stained.	Head and recess rusty and flaking, threads black, except under head, point rusty. Threaded hole gray but clean, hole rust stained.
No. 3 Cadmium 0.5 mil min + chromate + polysulfide sealant	Head and recess rusty, threads black with some coating still present. Threaded hole rusty, counterbore rusty.	Slight rusting on recess corners, white corrosion products under head and on top half of threads, point rusty. Threaded hole have white corrosion products, counterbore rust stained.	Head and recess rusty, threads black, point rusty. Threaded hole has black corrosion products, counterbore rust stained.
No. 4 Cadmium 0.2 mil min. + Zinc 0.3 mil + chromate	Head and recess rusty with attack on top. Threads black with white corrosion products in root. Threaded hole rusty, counterbore rusty.	Head and recess rusty, threads black and slightly rusty, point rusty. Threaded hole rusty, counterbore rust stained.	Head and recess rusty, threads black, point rusty. Threaded hole rusty, counterbore stained.
No. 5 Nickel electroless 0.6 mil	Head and recess rusty. Threads black, point rusty. Threaded hole very rusty, counterbore black.	Head flaking badly, threads black, point rusty. Threaded hole dirty, counterbore rust stained.	Head flaking, threads black point rusty. Threaded hole corroded, counterbore rust stained.
No. 6 Nickel electroplated 0.3 to 0.5 mil	Some plating on head, remainder rusty, threads black, point OK. Threaded hole very rusty, counterbore rusty.	Head rusty with some plating evident on top. Threads black, point clean. Threaded hole rusty, counterbore rust stained.	Some plating remaining on head threads black, point rusty. Threaded hole black but not rusty, counterbore rust stained.
No. 7 Nickel-cadmium diffused	Some plating on head, recess rusty. Threads black, point rusty. Threaded hole black, counterbore rusty.	Recess rusty, threads black, point rusty. Threaded hole black, counterbore slightly stained.	Head and recess rusty, threads black, point rusty. Threaded hole black, counterbore rust stained.
No. 8 SermeTel W 0.4 to 0.7 mil	Head and recess rusty, threads black, point rusty. Threaded hole rusty, counterbore rusty.	Recess rust stained, threads black, point rusty, Threaded hole black, counterbore stained.	Head and recess rusty, threads black, point rusty. Threaded hole black, counterbore rust stained.
No. 9 Zinc 0.3 to 0.5 mil + chromate	Head and recess rusty, threads black, point rusty. Threaded hole rusty, counterbore dirty.	Head rusty and flaking, thread rusty. Threaded hole rusty, counterbore rust stained.	Head rusty and flaking, threads rusty. Threaded hole rusty, counterbore rust stained.
No. 10 Zinc 0.5 mil min. + Chromate	Head and recess rusty, threads black. Threaded hole slightly rusty, counterbore rusty.	Head and recess rusty, threads slightly rusty. Threaded hole rusty, counterbore rust stained.	Head rusty and flaking, threads black. Threaded hole rusty, counterbore rust stained.
No. 11 Zinc 0.5 mil min. + chromate + polysulfide sealant	Head and recess flaking, threads dirty, point rusty. Threaded hole rusty, counterbore rusty.	Head and recess rusty, threads black, point rusty. Threaded hole slightly rusty, counterbore rust stained.	Head and recess flaking, threads silver gray with some rust staining. Threaded hole slightly rusty, counterbore rust stained.
No. 12 Zinc 0.2 mil + cadmium 0.3 mil + chromate	Head and recess rusty, threads have white corrosion products, point rusty. Threaded hole rusty, Counterbore rusty.	Head and recess slightly rusty, threads black, point rusty. Threaded hole black, counterbore rust stained.	Head and recess flaking, threads black. Threaded hole black but not very rusty, counterbore rust stained.

TABLE XXII

Long Term Low Temperature Test Results - 9 Months

Coating	Upper Plate Material: Steel HY80	Stainless Steel 304	Manganese Bronze
No. 1 Cadmium 0.3 to 0.5 mil + Chromate	a. Head and recess corroded. Threads black, counterbore and threaded hole rusty. b. Head corroded. Cad plate remaining on first 2 threads, Some on next five threads, remainder black. Counterbore and threaded hole rusty.	a. Top of head tapered and flaking off, black underneath and on threads. Counterbore dirty, threaded hole rusty. b. Some cadmium remaining on 7 threads from head down. Otherwise, same as above.	a. Head and recess badly corroded. Threads black. Counterbore rust stained. b. Bolt frozen in.
No. 2 Cadmium 0.5 mil min. + chromate	a. Head and recess rusty. Cad plate remaining on first two threads, some on next 6 threads. Counterbore and threaded hole rusty. b. Head and recess rusty. Threads black. Counterbore and threaded hole black.	a. Head and recess rusty. Cad remaining on 6 threads from head down. Counterbore dirty, threaded hole rusty. b. Head and recess rusty. Threads black, counterbore dirty, threaded hole rusty.	a. Head rusty. Plating remainin on 7 threads from head down. Counterbore clean from removed wiping action, threaded hole rusty. b. Bolt frozen in.
No. 3 Cadmium 0.5 mil min. + chromate + polysulfide Sealant	a. Head and recess rusty. Threads black. Counterbore rusty, threaded hole gray. b. Head and recess rusty. Threads have plating intact. Counterbore corroded, threads clean.	a. Rusty head and recess. Threads coated with sealant, counterbore stained, threads dirty but not rusty except under head in a few spots. b. Rusty head and recess. No significant difference from above except that sealant looks newer under head.	a. Rusty head and recess. Black threads and under head. Black counterbore and threaded hole. b. Rusty head and recess. Sealant still on threads. Counterbore stained, threads clean.
No. 4 Cadmium 0.2 mil min. + zinc 0.3 mil + chromate	a. Head and recess corroded. Threads have white corrosion products. Counterbore rusty, threaded hole has white corrosion products. b. Head and recess corroded. Threads black and rusty. Counterbore rusty. Threaded hole black.	a. Rusty head and recess, white corrosion products on threads and threaded hole. b. Rusty head and recess, rusty threads, threaded hole black.	a. Head and recess rusty. Threads black and slightly rusty. Threaded hole rusty. b. Head and recess rusty. Threads black. Counterbore and threaded hole black.
No. 5 Nickel electroless 0.6 mil	a. Corroded head and recess, rusty and black threads, black counterbore and threaded hole. b. Corroded head and recess, coating still on threads. Stained counterbore and black threaded hole.	a. Rusty head and recess, black threads, black counterbore and threaded hole. b. Rusty head and recess, threads dirty and slightly rusty. Threaded hole black.	a. Badly corroded head, threads black, counterbore and threaded hole black. b. Badly corroded head, threads dirty but plating intact. Threaded hole dirty.
No. 6 Nickel electroplated 0.3 to 0.5 mil	a. Head stained, recess rusty, threads rusty, counterbore and threaded hole rusty. b. Same as above.	a. Rust stained head, coating intact, threads black, threaded hole black. b. Same as above.	a. Stained head, coating still present, black threads, dirty counterbore, black threaded hole. b. Same as above.
No. 7 Nickel-cadmium diffused	a. Rust stained head, rusty recess, black threads and black threaded hole. b. Same as above.	a. Stained head, rusty recess, black threads, black threaded hole. b. Same as above.	a. Stained head, same as above. b. Same as above.
No. 8 SermeTel W 0.4 to 0.7 mil	a. Rusty head and recess, black threads and threaded hole. b. Same as above.	a. Slightly rusty head and recess, rusty threads, black threaded hole. b. Same as above.	a. Rusty head and recess, black threads, black threaded hole. b. Same as above.
No. 9 Zinc 0.3 to 0.5 mil + chromate	a. Rusty all over on bolt and threaded hole. b. Same as above except for white corrosion products on threads.	a. Rusty head and recess, black threads and threaded hole. b. Same as above.	a. Rusty head and recess, black threads and threaded hole. b. Same as above and white corrosion products on threads and in threaded hole.
No. 10 Zinc 0.5 mil min. + chromate	a. Rusty head and recess, white corrosion products and rust on threads, same in threaded hole. b. Rusty head and recess, rusty threads, black threaded hole.	a. Rusty head and recess, white and rusty products on threads, threaded hole rusty. b. Rusty all over, threaded hole rusty.	a. Rusty head and recess, white corrosion products on threads with rust. Threaded hole black. b. Rusty all over, threaded hole rusty.
No. 11 Zinc [illegible] mil min. + chromate + polysulfide sealant	a. Rusty head and recess, rusty threads, rusty counterbore. b. Rusty head and recess, clean threaded hole.	a. Rusty head and recess, rusty threads, rusty threaded hole. b. Rusty head and recess, clean threads and threaded hole.	a. Rusty head and threads, rusty threaded hole. b. Rusty head, clean threads, clean counterbore.
No. 12 Zinc 0.[illegible] mil + cadmium 0.3 mil + chromate	a. Rusty head and recess, white and gray threads, same in threaded hole. b. Rusty head and recess, white and rusty threads, rusty counterbore.	a. Rusty head and recess, light gray threads and clean hole. b. Rusty head and recess, rusty threads and rusty threaded hole.	a. Threads light grey, rusty head and recess, light grey counterbore. b. Rusty head and recess, black threads and threaded hole.

TABLE XXIII

Long Term High Temperature Test Results - 6 weeks

No.	Coating	Appearance
1.	None	Studs and nuts rusty, small number of rust spots on panel.
2.	Electroplated Nickel 0.4 mil	Nuts discolored, greenish deposit on studs. Panel coating blistering around nuts.
3.	Electroplated Nickel 0.7 mil	Nuts discolored, greenish deposit on studs. Panel coating blistering around nuts.
4.	Diffused Ni-Cad	Yellow-green color on studs and nuts. Panel coating blistering around nuts.
5.	Electroless Nickel 0.4 mil	Slight rusting on nut drive surfaces and stud threads. Panel blistering around nuts.
6.	Electroless Nickel 0.7 mil	Slight rusting on nut drive surfaces and stud threads. Very slight blistering evident on panel around nuts.
7.	Electroplated Nickel + SermeTel W	Nut edges slightly attacked, stud threads have yellow-green coating. Slight blistering on panel around nut.
8.	SermeTel W 0.4 - 0.7 mil 375°F cure	Slight blistering on panel around nuts. Dark products on stud threads. Nuts look good.
9.	SermeTel W 650°F - 15 min. 1000°F - 1 1/2 hr.	Slight blistering of panel around nuts. Studs rusting on threads. Nut edges darker than faces.
10.	Inconel 718 stud Waspaloy nut	Slight blistering of panel around nuts. White product evident on stud end is probably remains of dry film lubricant.

TABLE XXIV

Long Term High Temperature Test Results - 15 Weeks

No.	Coating	Appearance
1.	None	Studs and nuts rusty, severe rusting on sides and end of plates, faces slightly rusty.
2.	Electroplated Nickel 0.4 mil	Threads rusted slightly, rust stains on side of plate, blistering around nuts.
3.	Electroplated Nickel 0.7 mil	Slight rusting of threads and nut faces, sides and end of block. Severe lifting of coating around nuts.
4.	Diffused Ni-Cad	Stud ends and nuts rusty, severe rusting on sides and end of block. Severe lifting of coating around nuts.
5.	Electroless Nickel 0.4 mil	Slight rust stains on sides and end of block. Slightly rusty threads and nuts, slight lifting around nuts.
6.	Electroless Nickel 0.7 mil	Rust stains on sides and end of block. Slight rusting of nuts and threads. Slight lifting around nuts.
7.	Electroplated Nickel + SermeTel W	Rust stains on sides and end of block. Slight lifting around nuts.
8.	SermeTel W 0.4 - 0.7 mil 375°F cure	Rust stains on side and end of blocks. Slight rusting in threads, slight lifting around nuts.
9.	SermeTel W 650°F - 15 min. 1000°F - 1 1/2 hr.	Slight rusting on nut faces, rust stains on side and end of blocks, slight lifting around nuts.
10.	Inconel 718 Stud Waspaloy Nut	Excellent compatibility. Slight lifting or extrusion of aluminum coating under one nut.

TABLE XXV

Long Term High Temperature Test Results - 9 Months

No.	Coating	Appearance
1.	None	Studs and nuts rusty, severe rusting on sides and end of plates, faces rusting in localized areas.
2.	Electroplated Nickel 0.4 mil	Small degree of rust in threads and on ends of studs. Plate sides and ends rusty, coating consumed around holes at end of plate, less consumed around interior holes.
3.	Electroplated Nickel 0.7 mil	Almost rust free threads, nuts rust free except for some on internal threads. Severe depletion of aluminum coating on plate around holes, rusting of sides and ends.
4.	Diffused Ni-Cad	Rusting on stud ends and nuts, sides and ends of blocks. Coating consumed around holes at end of plate.
5.	Electroless Nickel 0.4 mil	Studs and nuts rusty, severe rusting of plate sides and ends. Complete consummation of coating around all holes.
6.	Electroless Nickel 0.7 mil	Rusty studs and nuts, not as severe as above. Rusting ends and sides of plate, coating consumed around holes near end.
7.	Electroplated Nickel + SermeTel W	Very slight rusting on studs and nuts, little loss of coating around holes.
8.	SermeTel W 0.4 - 0.7 mil 375°F cure	Rusting especially evident on threads of studs and nuts as well as stud shank. Plate coating attacked slightly around holes but rusty on sides and ends.
9.	SermeTel W 650°F - 15 min. 1000°F - 1 1/2 hr.	Rusting especially evident on threads of studs and nuts as well as stud shank. Plate coating attacked slightly around holes but rusty on sides and ends.
10.	Inconel 718 Stud Waspaloy Nut	Slight discoloration of Inco 718 stud. Some hard to remove rust stains on nut. Depletion of coating around some holes, sides and ends rusty.

TABLE XXVI

Breakaway Torques for 3/4-10 Studs and Nuts in Hi Temperature Test

Panel & Stud No.*	Foot-Pounds Front	Foot-Pounds Rear	Stud & Nut Coating System	Panel & Stud No.*	Foot-Pounds Front	Foot-Pounds Rear	Stud & Nut Coating System
1 - 1	425	100		6 - 1	225	100	Electroless
1 - 2	75	125	Bare	6 - 2	200	75	Nickel
1 - 3	400	225		6 - 3	100	50	0.0007"
1 - 4	375	150		6 - 4	250	50	
2 - 1	325	175	Electroplated	7 - 1	450	300	Electroplated
2 - 2	375	125	Sulfamate	7 - 2	350	75	Sulfamate Nickel
2 - 3	250	150	Nickel	7 - 3	200	125	0.0003" and
2 - 4	325	125	0.0004"	7 - 4	325	75	SermeTel W
							0.0003 to 0.0007"
3 - 1	350	150	Electroplated	8 - 1	350	275	SermeTel W
3 - 2	325	175	Sulfamate	8 - 2	400	125	per AMS 2506
3 - 3	100	50	Nickel	8 - 3	225	175	0.0003" to
3 - 4	375	125	0.0007"	8 - 4	450	200	0.0007"
4 - 1	300	50	Diffused	9 - 1	375	150	SermeTel W
4 - 2	275	100	Nickel-	9 - 2	375	150	0.0004 to 0.0007"
4 - 3	175	0	Cadmium per	9 - 3	250	175	15 min. at 650°F
4 - 4	300	25	AMS 2416	9 - 4	375	150	1.5 hr at
							1000°F
5 - 1	275	200	Electroless	10 - 1	250	0	Inconel 718
5 - 2	275	175	Nickel	10 - 2	275	0	Studs
5 - 3	300	125	0.0004"	10 - 3	0	0	Waspaloy Nuts
5 - 4	300	150		10 - 4	200	0	

Note 1. *Location is shown in sketch:

Panel No.

1 2
3 4

Note 2. All threaded surfaces initially coated with MIL-L-46010 (MR) (Sandstrom 9A) dry film lubricant

TABLE XXVII

Breakaway Torques for 3/4-10 Studs and Nuts in Exposure Racks

No.	Coating System	Saratoga Torque, Foot-Pounds	Ranger Torque, Foot-Pounds
1.	Bare	200	0
		200	150
2.	Diffused	150	150
	Nickel-Cadmium	150	125
3.	Electroplated	175	125
	Nickel, 0.7 mil	150	125
4.	Electroless	200	0
	Nickel, 0.4 mil	225	125
5.	Electroplated	150	175
	Nickel, 0.4 mil	175	150
6.	Inconel 718 Stud	75	125
	Waspaloy Nut	125	125

TABLE XXVIII

Results of Exposure aboard U.S.S. Saratoga for 6 Months

No.	Coating System	Results
1.	Bare	Extremely rusty all over except on engaged threads.
2.	Diffused Nickel-Cadmium	White corrosion products on nut flats and stud ends. Free spinning nut on stud.
3.	Electroplated Nickel, 0.7 mil	No corrosion evident except for rust stains from adjacent rusting angle. Free spinning nut on stud.
4.	Electroless Nickel, 0.4 mil	Rusty stud and nuts except for engaged threads. Plating lifting off from corrosion products.
5.	Electroplated Nickel, 0.4 mil	Extremely light rust in outer threads of nuts. Studs exceptionally clean. Free spinning nut on stud.
6.	Inconel 718 Stud Wasplaoy Nut	No corrosion. Free spinning nut on stud.

TABLE XXIX

Metal Sprayed Coating Corrosion Test Results

Code	Thickness, mil	Coating	Result
A	.002	Aluminum (wire spray) After 1000 hr. 5% salt spray	Red rust in recess bottom, underhead, and on threads of large bolt. White corrosion products all over. Red rust in recess bottom of small bolts, white corrosion products all over.
A	.003	Aluminum (Wire spray) After 1000 hr. 5% salt spray	Red rust in recess bottom and underhead on large bolt. White corrosion products all over. Red rust in bottom of recess of small bolts.
AM	.002	Aluminum/ Molybdenum After 7 days 5% salt spray	90% of large bolt has red rust, remainder has white corrosion products.
AM	.002	Aluminum/ Molybdenum Heat treated After 7 days 5% salt spray	95% of large bolt has red rust, remainder has white corrosion products.
AM	.003	Aluminum/ Molybdenum After 7 days 5% salt spray	95% of large bolt has red rust, remainder has white corrosion products.
AM	.003	Aluminum/ Molybdenum Heat treated After 7 days 5% salt spray	50% of large bolt has red rust, remainder has white corrosion products
AMP	.002	Aluminum/ MP35N After 1000 hr. 5% salt spray	Red rust on head, in recess, around head and on threads of large bolt. White corrosion products on remainder of area and on small bolts.
AMP	.002	Aluminum/ MP35N Heat treated After 1000 hr. 5% salt spray	Red rust top of head and recess of large bolt. White corrosion products on remainder of area and on small bolts.
AMP	.003	Aluminum/ MP35N After 1000 hr. 5% salt spray	Red rust and white corrosion products everywhere on large bolt. Red rust on heads of small bolts. White corrosion product all over.

TABLE XXIX - (Continued)

Metal Sprayed Coating Corrosion Test Results

Code	Thickness, mil	Coating	Result
AMP	.003	Aluminum/ MP35N Heat treated	Red rust in recess and around head. White corrosion product all over. Coating flaking off. Coarse thread small bolt has red rust on head and in recess. Fine thread has red rust in recess. Both have white corrosion products.
	After 1000 hr. 5% salt spray		
AT	.002	Aluminum/ Titanium	Red rust on 75% of big bolt. White corrosion products elsewhere.
	After 552 hr. 5% salt spray		
AT	.002	Aluminum/ Titanium	Red rust in recess bottom around head of both small bolts.
	After 1000 hr. 5% salt spray		
AT	.003	Aluminum/ Titanium	Red rust in recess bottom and around head. White corrosion products all over.
	After 1000 hr. 5% salt spray		
MP	.002	Multiphase MP35N	Red rust 100% of area all three bolts.
	After 7 days 5% salt spray		
MP	.003	Multiphase MP35N	Red rust 100% of area all three bolts.
	After 7 days 5% salt spray		
NA	.002	Nickel Aluminide/ Aluminum	No red rust. White corrosion products all over the three nuts.
	After 1000 hr. 5% salt spray		
NA	.003	Nickel Aluminide/ Aluminum	Red rust in recess bottom and spotty elsewhere. Fine thread bolt rusty over 50% of area.
	After 1000 hr. 5% salt spray		
T	.002	Titanium	Red rust 100% of area all three bolts.
	After 7 days 5% salt spray		
T	.003	Titanium	Red rust 100% of area all three bolts.
	After 7 days 5% salt spray		
Z	.002	Zinc	White corrosion products and red rust all over on large and coarse thread bolts. Slight red rust in recess and around head of fine thread bolt.
	After 1000 hr. 5% salt spray		

TABLE XXIX - (Continued)

Metal Sprayed Coating Corrosion Test Results

Code	Thickness, mil	Coating	Results
Z	.003	Zinc	Red rust and white corrosion products all over on all three bolts.
	After 1000 hr. 5% salt spray		
ZA	.002	Zinc/ Aluminum	White corrosion products on all three bolts. No red rust evident.
	After 1000 hr. 5% salt spray		
ZA	.003	Zinc/ Aluminum	White corrosion products on all three bolts. No red rust evident.
	After 1000 hr. 5% salt spray.		

TABLE XXX

Corrosion Rates of Selected Coating Systems
MPY at 4.5 Months

System	Initial	Steel Top Plate	SS Top Plate	Mn - Br Top Plate
1. Cad + Chromate	6.29	.50	.052	.196
2. Cad + Chromate	4.15	.203	.041	.65
3. Cad + Chromate + Polysulfide	.39	1.04	.98	.56
4. Cad + Zinc + Chromate	3.01	24.8	14.72	.46
5. Electroless Nickel	8.25	24.2	.87	1.05
6. Electroplated Nickel	1.03	11.5	15.1	10.7
7. Diffused Nickel-Cadmium	5.96	63.3	43.9	36.3
8. SermeTel W	.34	20.31	16.33	31.04
9. Zinc + Chromate	1.88	.047	15.7	.13
10. Zinc + Chromate	1.92	13.27	8.43	9.94
11. Zinc + Chromate + Polysulfide	.027	.027	3.25	.012
12. Zinc Cad + Chromate	1.3	.080	12.04	.013

TABLE XXXI

Corrosion Potentials of Selected Coating Systems
(Volts) Ag - AgCl Ref. at 4.5 Months

System	Initial	Steel Top Plate	SS Top Plate	Mn - Br Top Plate
1. Cad + Chromate	-.77	-.66	-.63	-.59
2. Cad + Chromate	-.77	-.69	-.69	-.53
3. Cad + Chromate + Polysulfide	-.76	-.71	-.71	-.83
4. Cad + Zinc + Chromate	-1.05	-.49	-.46	-.45
5. Electroless Nickel	-.42	-.22	-.39	-.60
6. Electroplated Nickel	-.53	-.29	-.42	-.33
7. Diffused Nickel-Cadmium	-.66	-.23	-.23	-.21
8. SermeTel W	-.75	-.32	-.46	-.16
9. Zinc + Chromate	-1.10	-.57	-.53	-.46
10. Zinc + Chromate	-1.07	-.52	-.54	-.51
11. Zinc + Chromate + Polysulfide	-1.02	-.98	-.53	-.84
12. Zinc + Cad + Chromate	-.93	-.69	-.54	-.41

TABLE XXXII

Corrosion Rates of Selected Coating Systems
MPY at 9 Months

System	Initial	Steel Top Plate I	Steel Top Plate II	SS Top Plate I	SS Top Plate II	Mn - Br Top Plate I	Mn - Br Top Plate II
1. Cad + Chromate	6.29	26.19	15.00	20.36	14.25	25.69	17.21
2. Cad + Chromate	4.15	26.01	16.99	25.29	25.00	27.29	22.45
3. Cad + Chromate + Polysulfide	.39	13.81	11.96	9.03	11.82	18.97	13.95
4. Cad + Zinc + Chromate	3.01	23.41	14.83	18.58	3.27	28.34	24.28
5. Electroless Nickel	8.25	15.18	16.93	14.34	23.34	36.12	14.34
6. Electroplated Nickel	1.03	45.90	10.24	24.77	10.84	29.48	14.24
7. Diffused Nickel-Cadmium	5.96	11.97	14.30	6.69	9.54	8.37	9.75
8. SermeTel W	.34	24.68	13.55	21.96	8.94	16.25	10.61
9. Zinc + Chromate	1.88	22.50	11.17	19.71	12.45	8.96	12.36
10. Zinc + Chromate	1.92	22.40	10.23	22.33	10.30	17.03	11.13
11. Zinc + Chromate + Polysulfide	.027	11.29	13.21	6.98	12.26	9.96	13.73
12. Zinc + Cad + Chromate	1.3	17.96	12.90	19.92	5.96	32.91	14.45

Note I. Removed and reinstalled after 4.5 months
II. Removed only after 9 months

TABLE XXXIII

Corrosion Potentials of Selected Coating Systems
(Volts) Ag - AgCl Ref. at 9 Months

System	Initial	Steel Top Plate I	Steel Top Plate II	SS Top Plate I	SS Top Plate II	Mn - Br Top Plate I	Mn - Br Top Plate II
1. Cad + Chromate	-.77	-.53	-.57	-.52	-.55	-.53	-.56
2. Cad + Chromate	-.77	-.51	-.64	-.52	-.64	-.53	-.65
3. Cad + Chromate + Polysulfide	-.76	-.54	-.65	-.54	-.64	-.54	-.66
4. Cad + Zinc + Chromate	-1.05	-.52	-.62	-.53	-.55	-.52	-.55
5. Electroless Nickel	-.42	-.52	-.51	-.52	-.50	-.53	-.53
6. Electroplated Nickel	-.53	-.49	-.50	-.50	-.49	-.51	-.51
7. Diffused Nickel-Cadmium	-.66	-.49	-.51	-.46	-.47	-.49	-.51
8. SermeTel W	-.75	-.50	-.54	-.52	-.55	-.51	-.54
9. Zinc + Chromate	-1.10	-.52	-.51	-.52	-.51	-.51	-.52
10. Zinc + Chromate	-1.07	-.53	-.53	-.53	-.53	-.54	-.52
11. Zinc + Chromate + Polysulfide	-1.02	-.51	-.85	-.54	-.85	-.53	-.93
12. Zinc + Cad + Chromate	-.93	-.52	-.52	-.53	-.66	-.51	-.64

Note I. Removed and reinstalled after 4.5 months
II. Removed only after 9 months

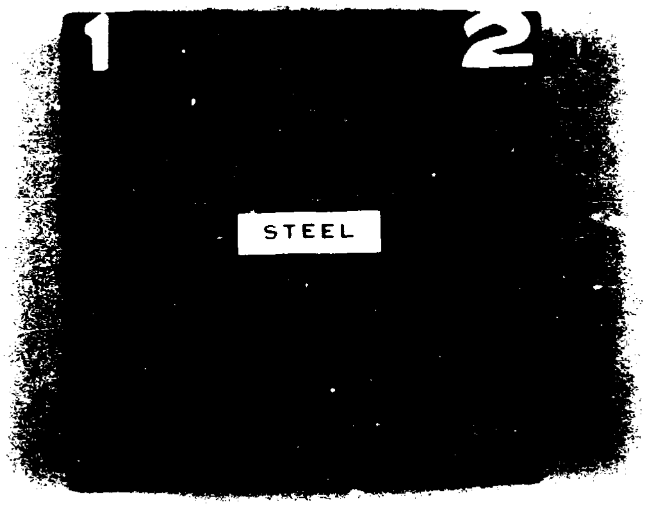


Photo 1. 9 month exposure of cadmium plating in steel block at Ocean City produced severe rusting in steel block. See Table XXII.

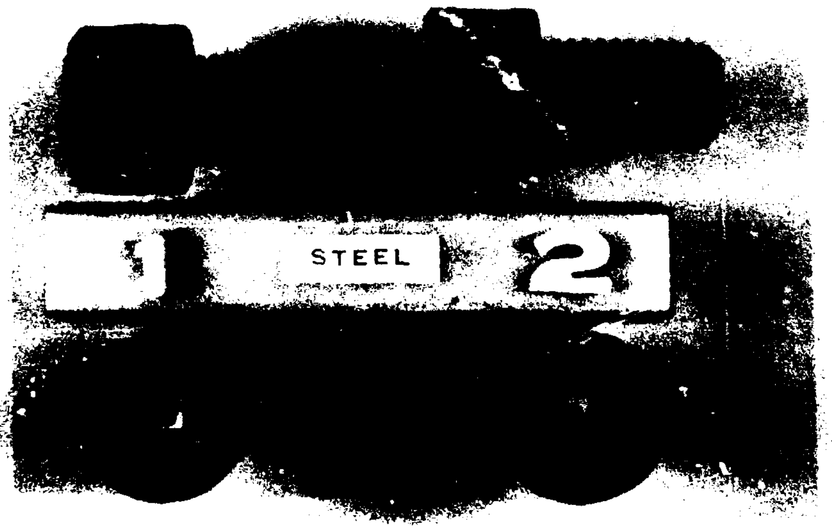


Photo 2. Neither cadmium plating system lasted the 9 month exposure at Ocean City. See Table XXII.

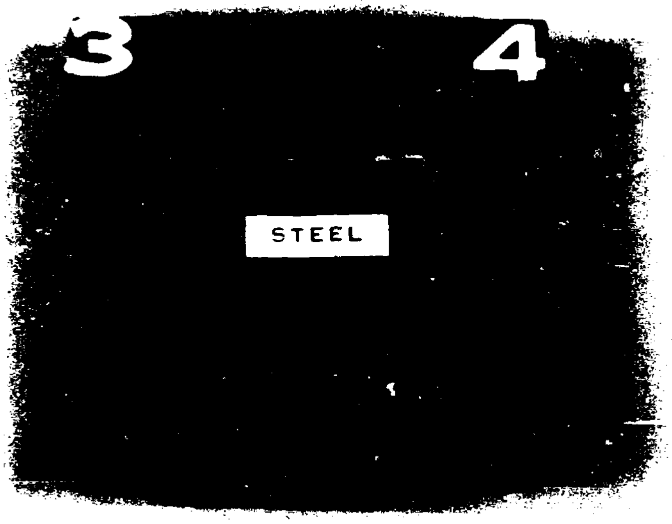


Photo 3. 9 month exposure at Ocean City produced severe rusting of steel block. See Table XXII.

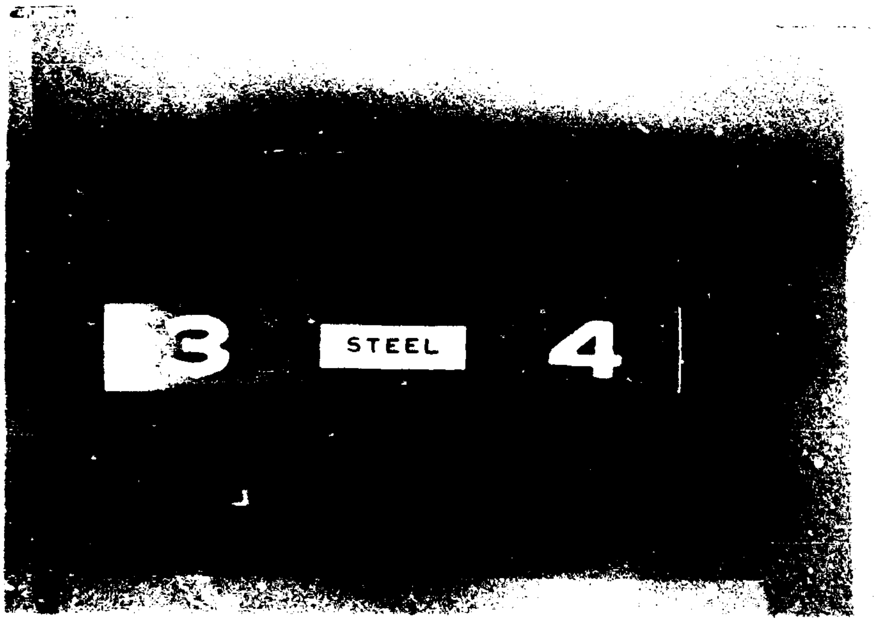


Photo 4. The sealant system(3) offered protection to the threads but the cadmium + zinc(4) allowed rusting after 9 months exposure at Ocean City. See Table XXII.

Photo 5. Electroless nickel(5) was not protective but electroplated nickel(6) protected the head well after 9 months exposure at Ocean City. See Table XXII.

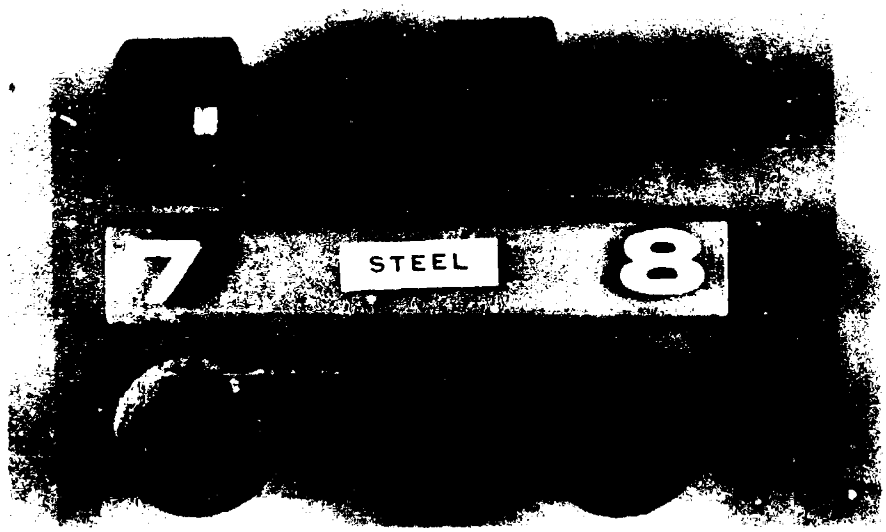


Photo 6. Diffused Ni-Cd(7) protected the head whereas SermeTel W(8) did not after 9 months exposure at Ocean City. See Table XXII.

ong term Exposure

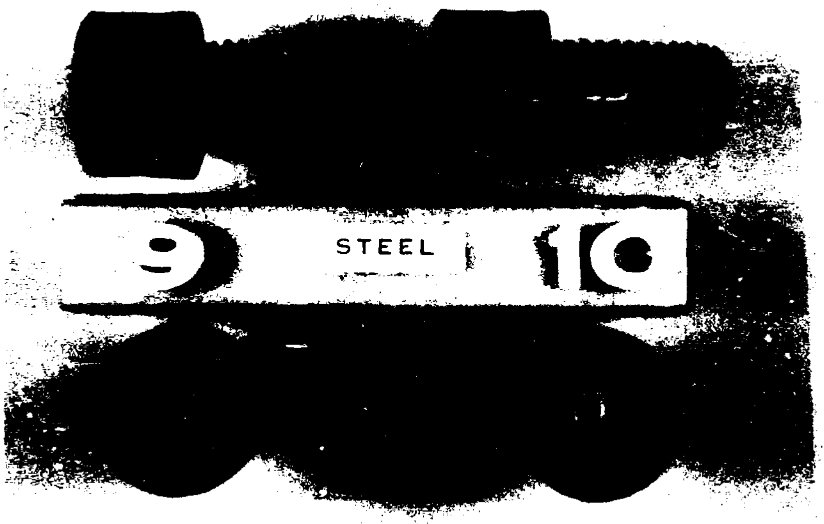


Photo 7. Neither zinc plating system lasted the 9 month exposure at Ocean City. See Table XXII.

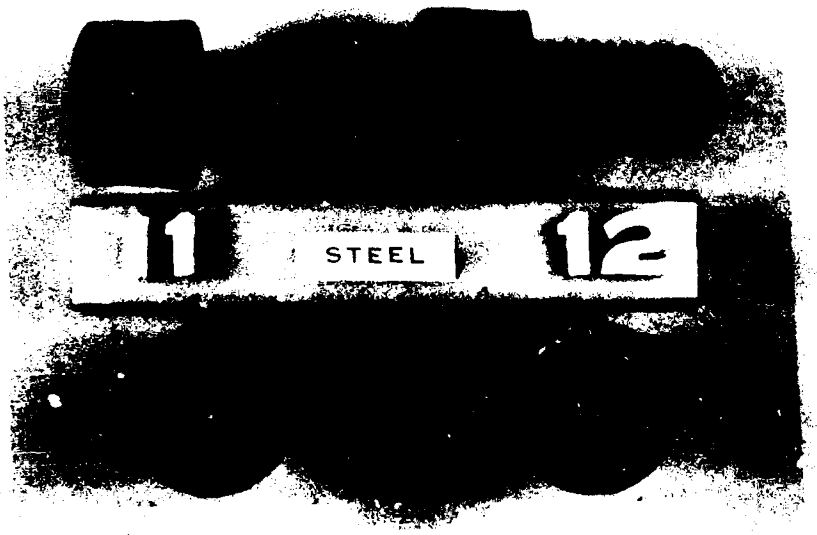


Photo 8. The sealant system(11) and the zinc + cadmium system(12) offered protection to the threads after 9 months exposure at Ocean City. See Table XXII.

Temperature Long Term Exposure

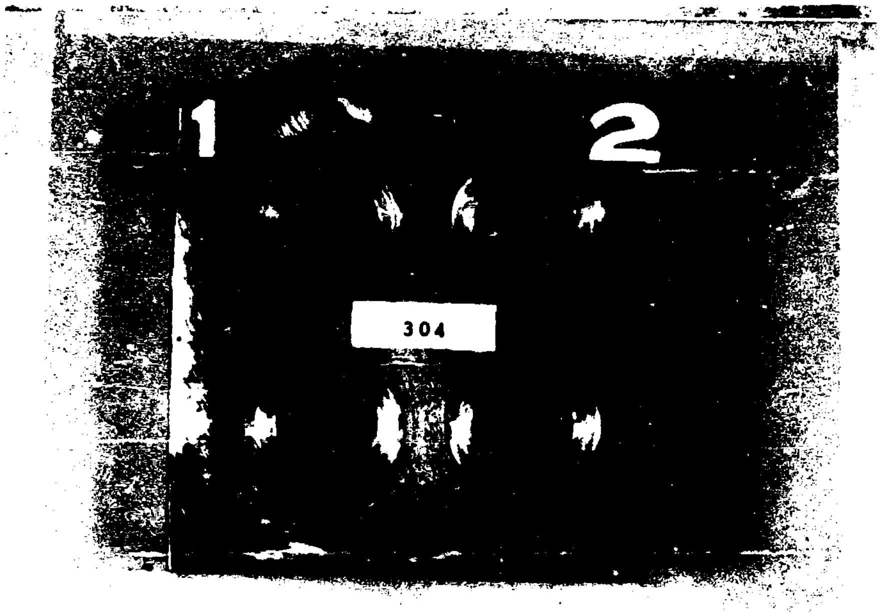


Photo 9. 9 month exposure at Ocean City produced no corrosion of stainless steel block. See Table XXII.

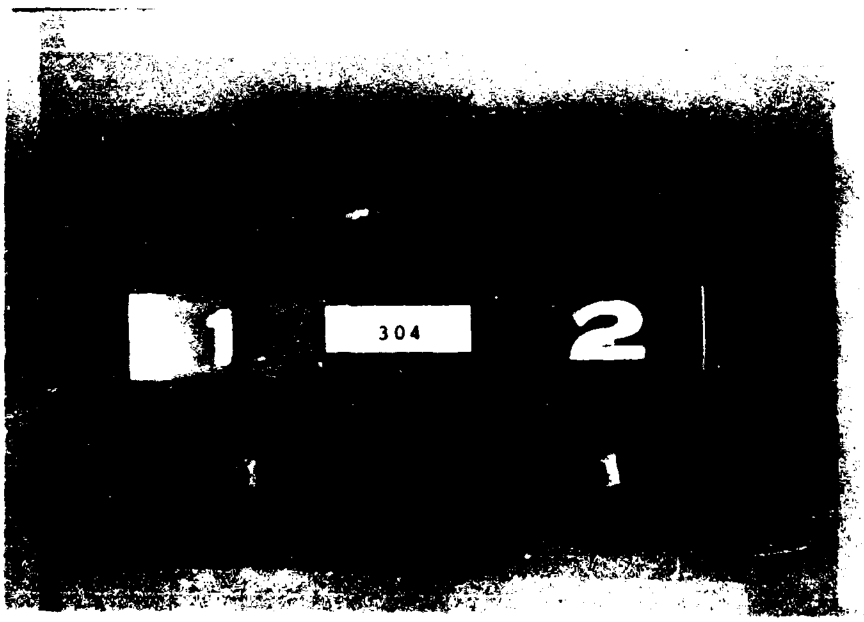


Photo 10. Neither cadmium plating system lasted the 9 month exposure at Ocean City. See Table XXII.

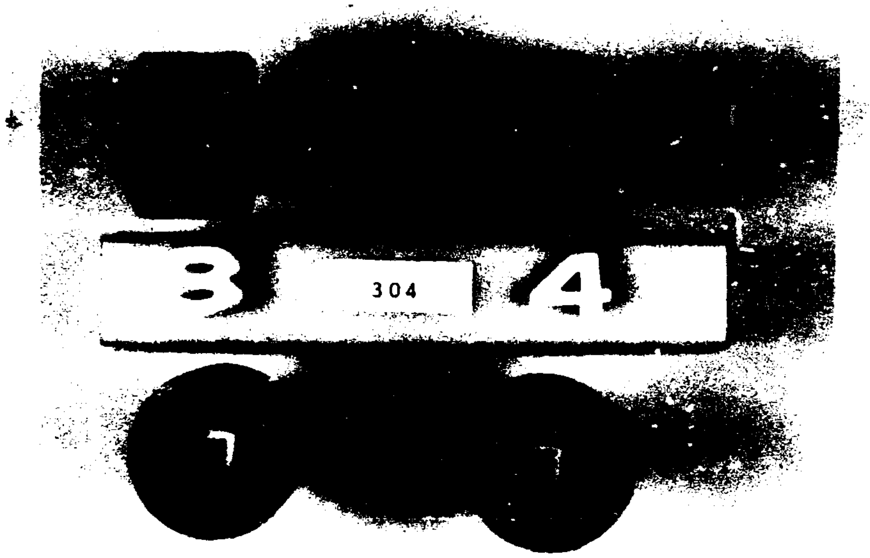


Photo 11. The sealant system(3) offered protection to the threads whereas the cadmium + zinc(4) allowed some rusting after 9 months exposure at Ocean City. See Table XXII.

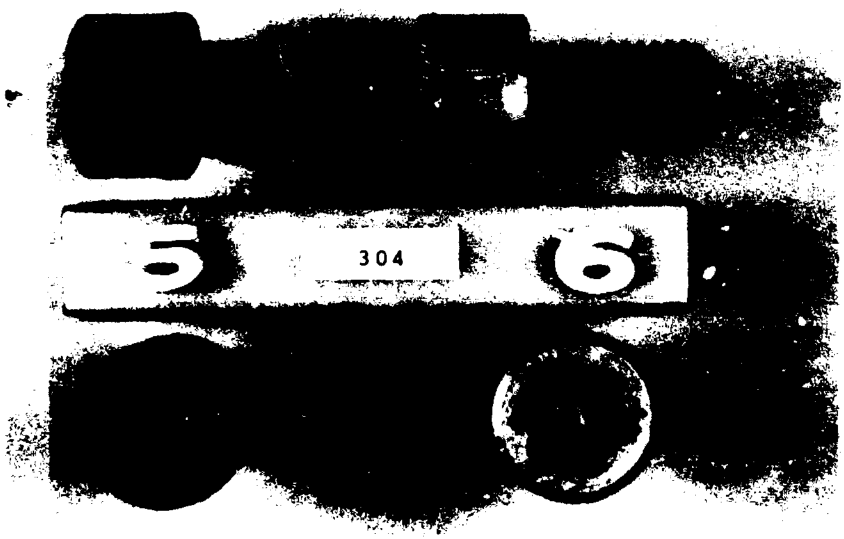


Photo 12. Electroless nickel(5) was not protective but electroplated nickel (6) protected the head well after 9 months exposure at Ocean City. See Table XXII.

Low Temperature Long Term Exposure

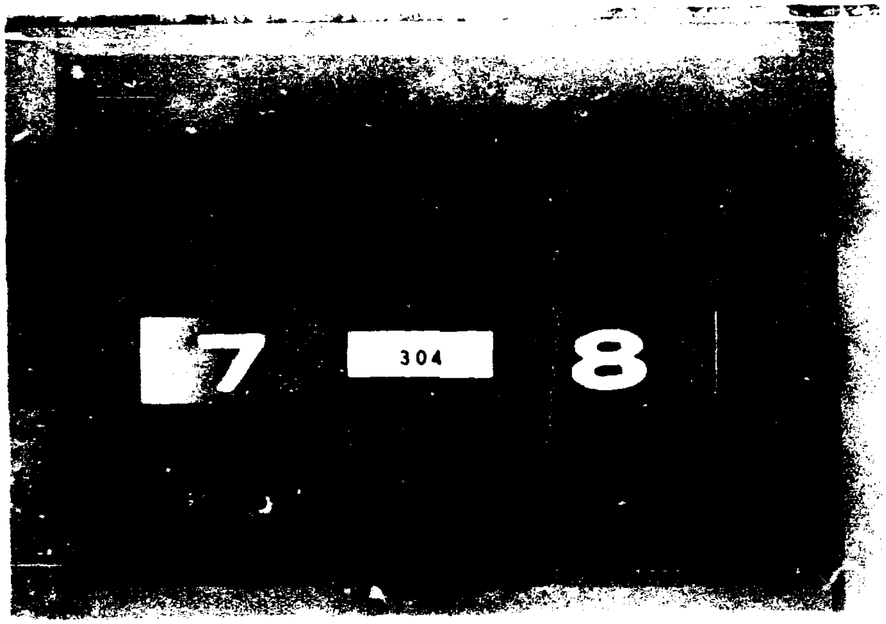


Photo 13. Diffused Ni-Cd(7) protected the head whereas SermeTel W(8) did not after 9 months exposure at Ocean City. See Table XXII.

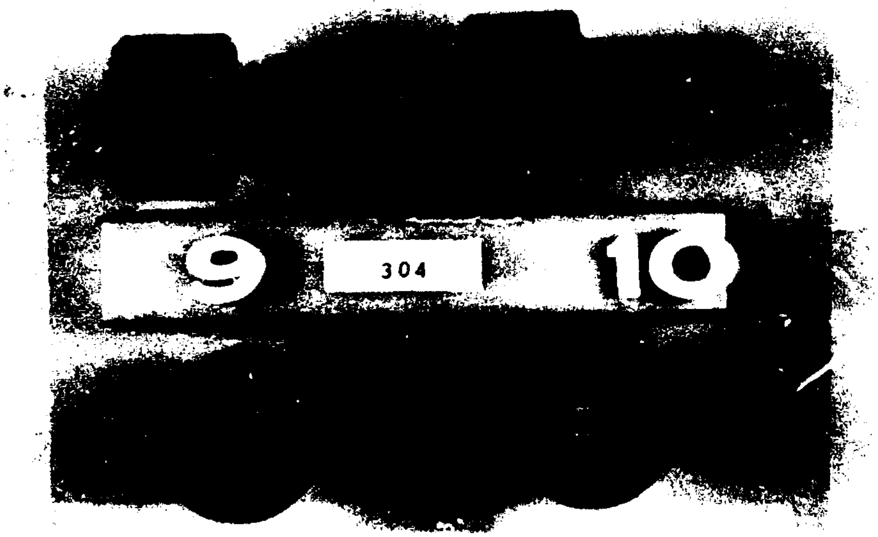


Photo 14. Neither zinc plating system lasted the 9 month exposure at Ocean City. See Table XXII.

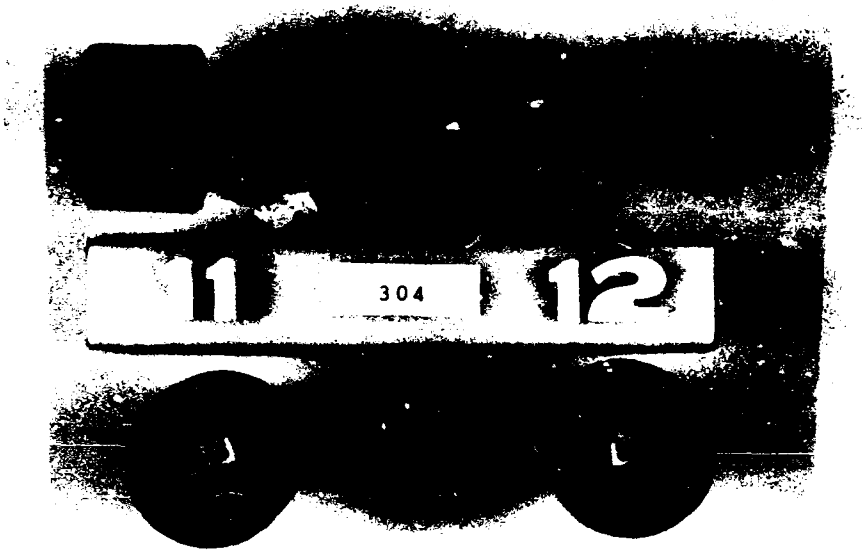


Photo 15. The sealant system(11) and the zinc + cadmium system(12) offered protection to the threads after 9 months exposure at Ocean City. (see Table XXII.

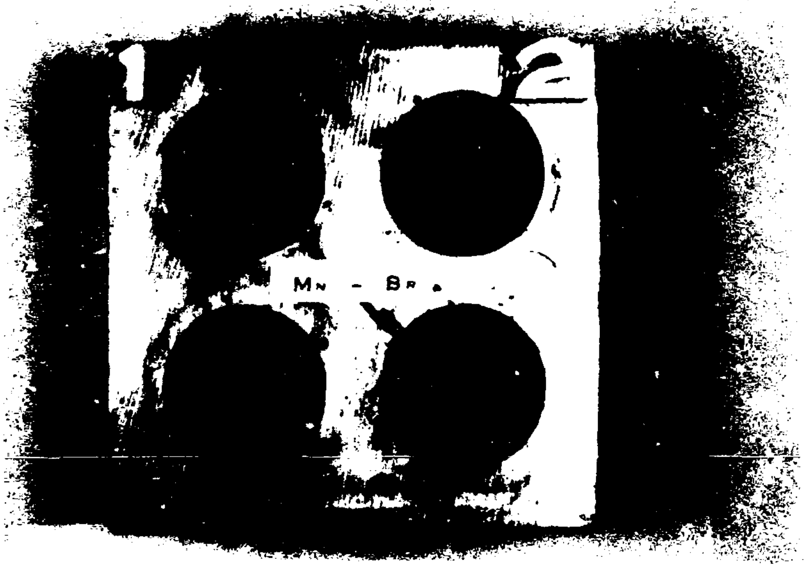


Photo 16. 9 month exposure of cadmium platings at Ocean City produced no corrosion of manganese bronze block. See Table XXII.

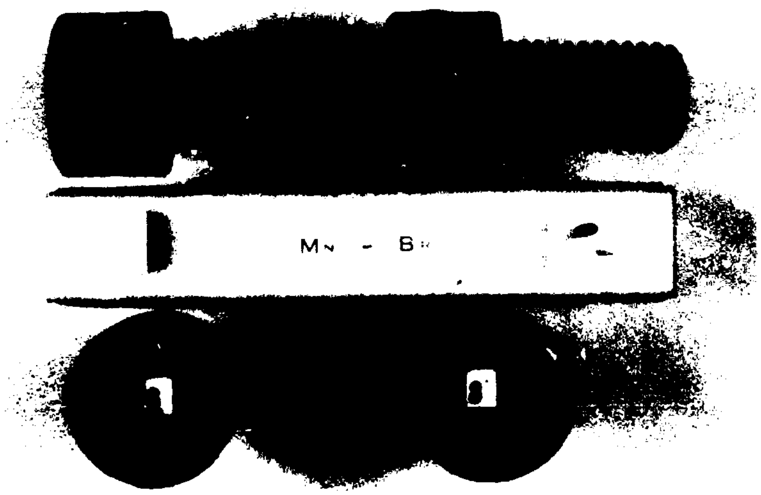


Photo 17. Neither cadmium plating system lasted the 9 month exposure at Ocean City. See Table XXII.

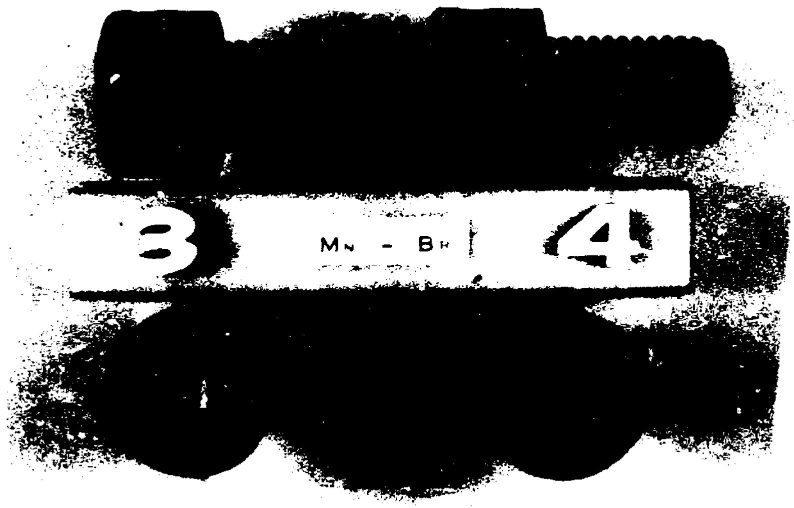


Photo 18. [illegible] system(3) offered protection to the [illegible] the cadmium + zinc(4) allowed rusting [illegible] exposure [illegible] Ocean City. See Table XXII.

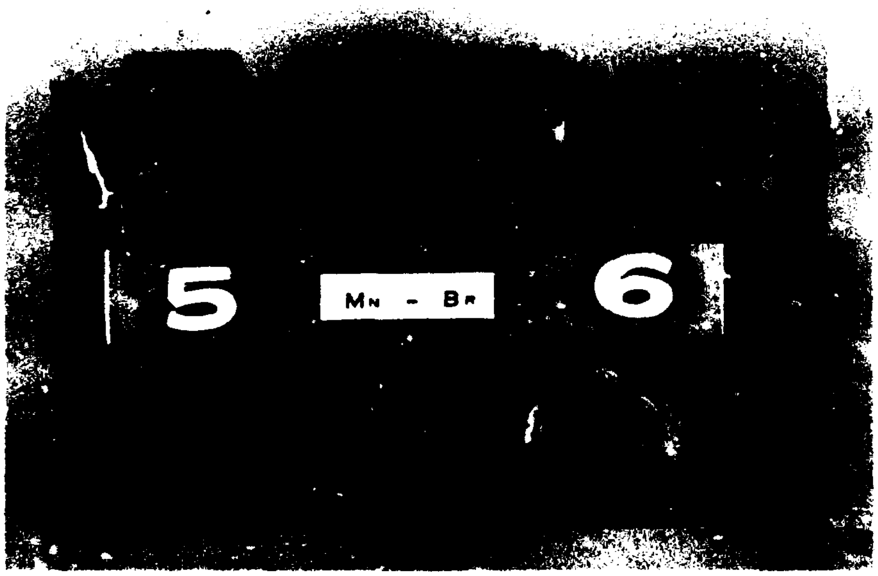


Photo 19. Electroless nickel(5) was not protective but electroplated nickel(6) protected the head well after 9 months exposure at Ocean City. See Table XXII.

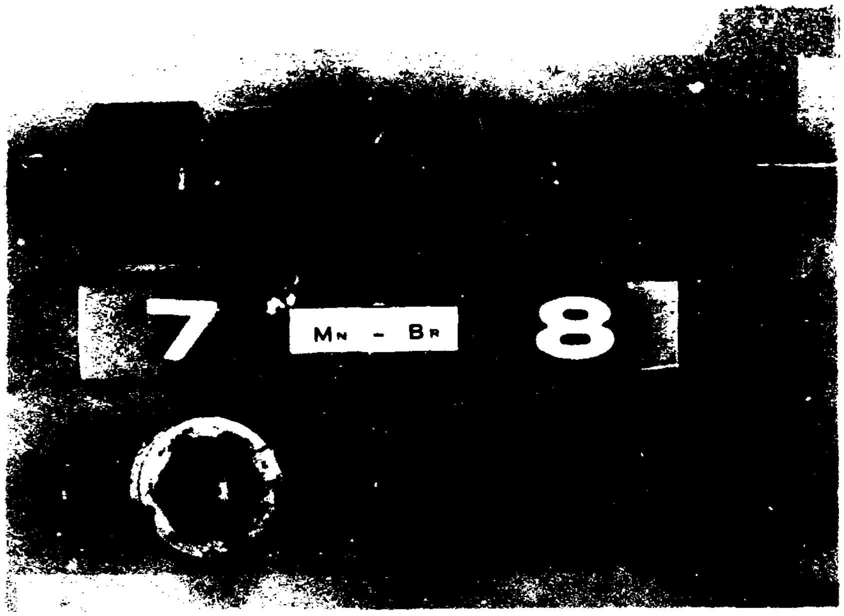


Photo 20. Diffused Ni-Cd(7) protected the head whereas SermeTel W(8) did not after 9 months exposure at Ocean City. See Table XXII.

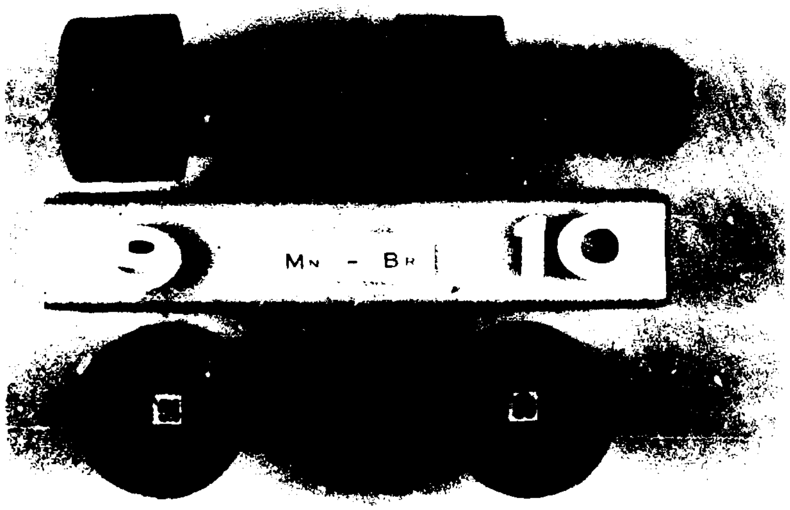


Photo 21. Neither zinc plating system lasted the 9 month exposure at Ocean City. See Table XXII.

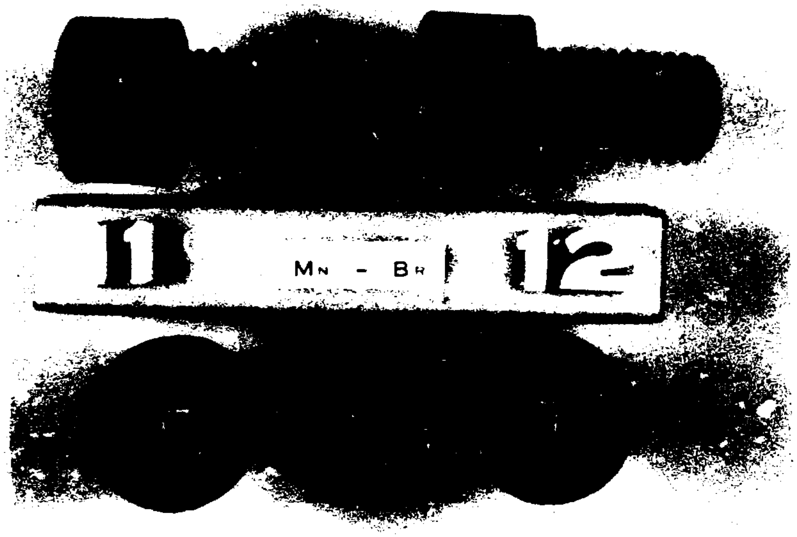


Photo 22. The sealant system(11) and the zinc + cadmium system(12) offered protection to the threads after 9 months exposure at Ocean City. See Table XXII.

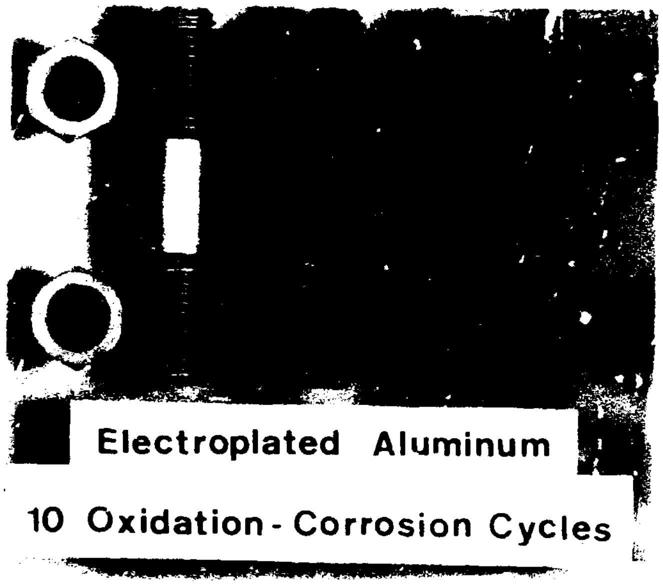


Photo 23

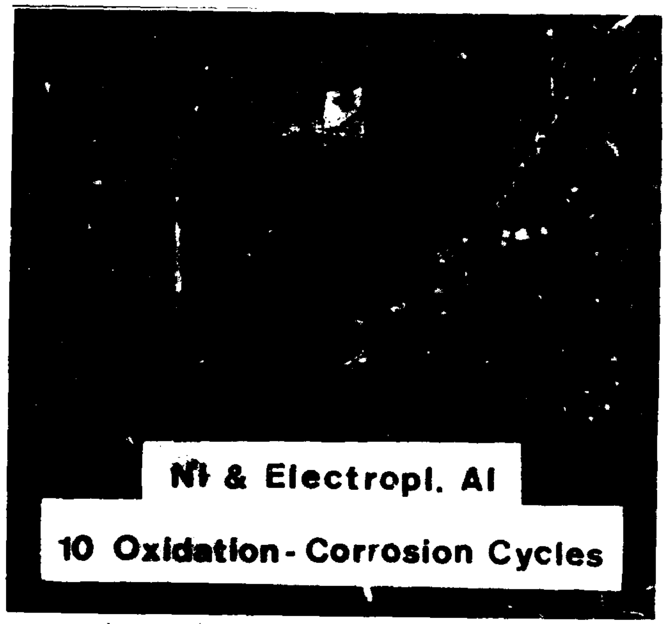


Photo 24.

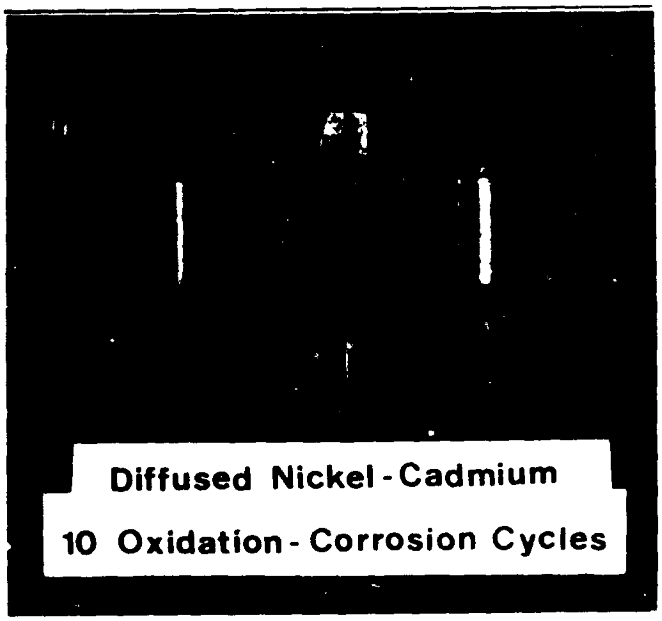


Photo 25.

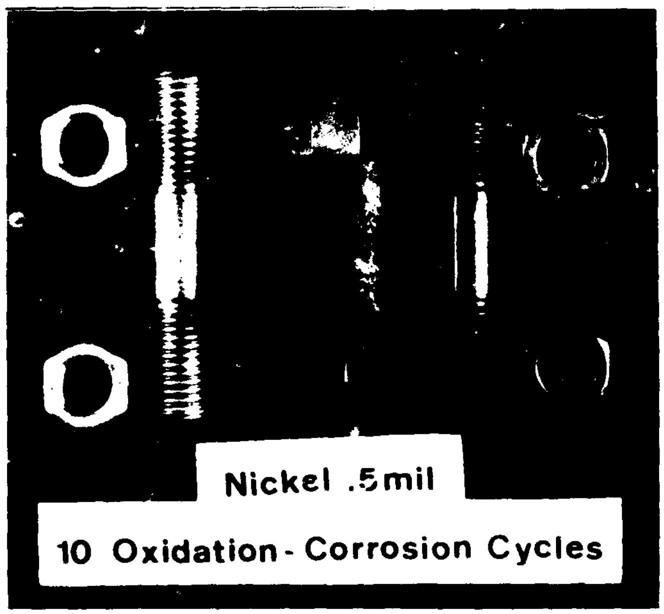


Photo 26.

High Temperature Screening Test Results. Unexposed specimens are on the left, exposed in the center, and disassembled exposed on the right.

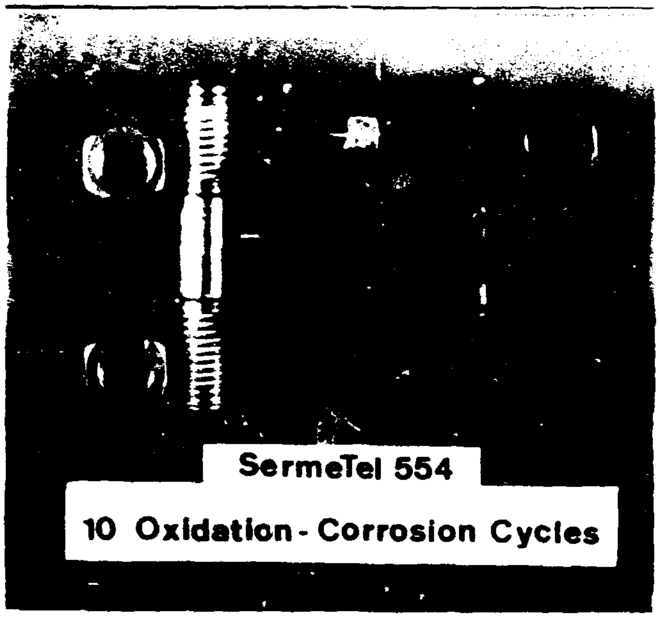


Photo 27.

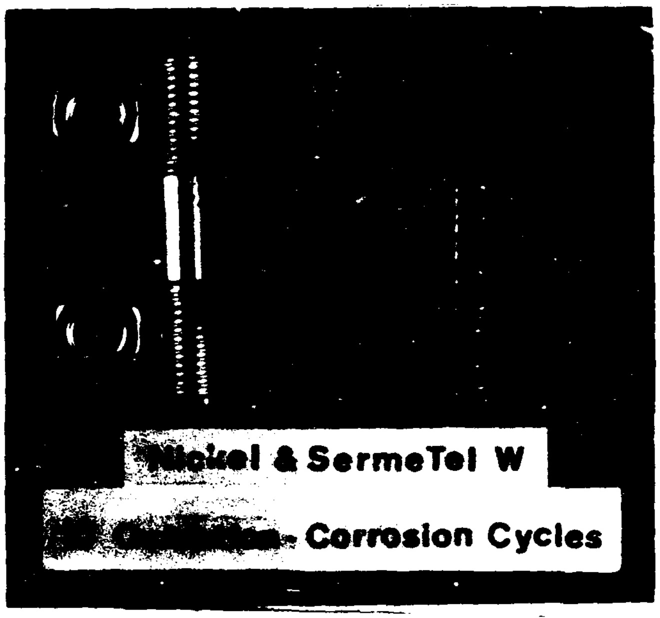


Photo 28.

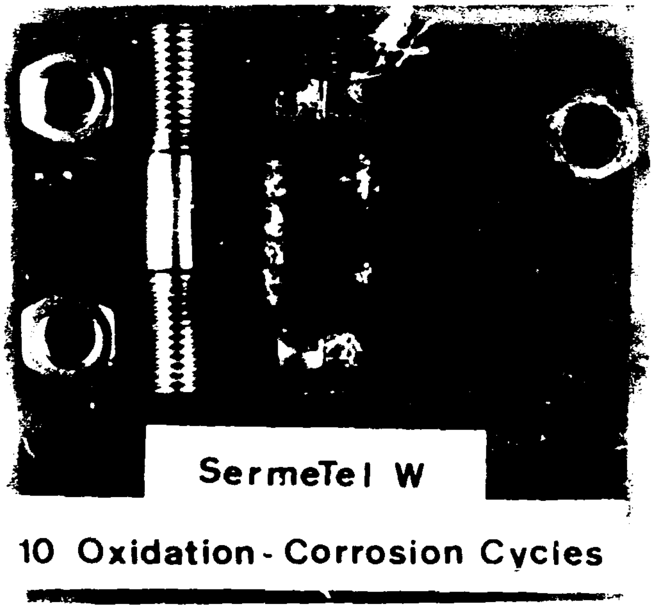


Photo 29.

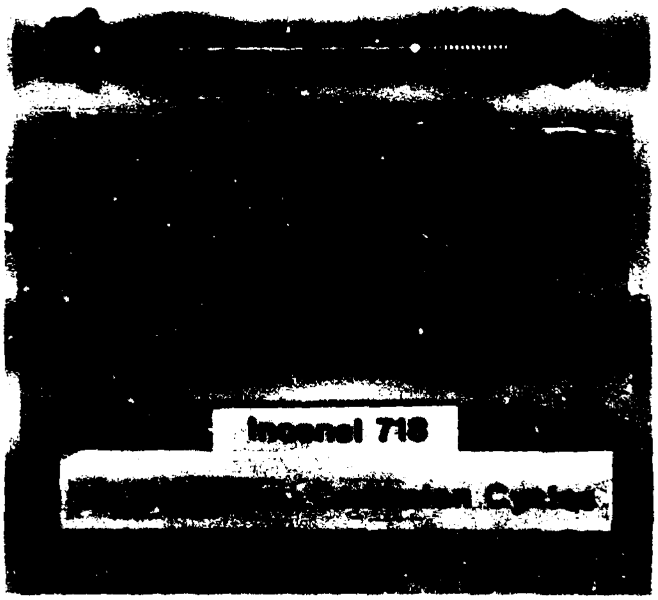


Photo 30.

High temperature screening test Results. Unexposed specimens are on the left, exposed in the center, and disassembled exposed on the right.

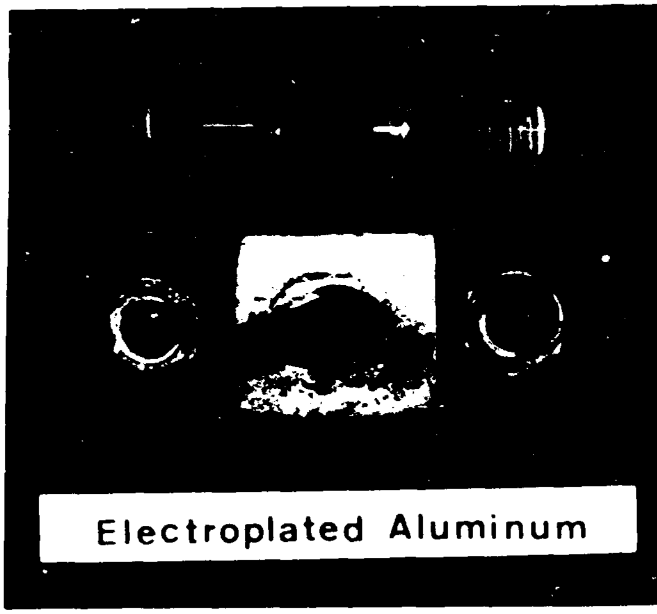


Photo 31.

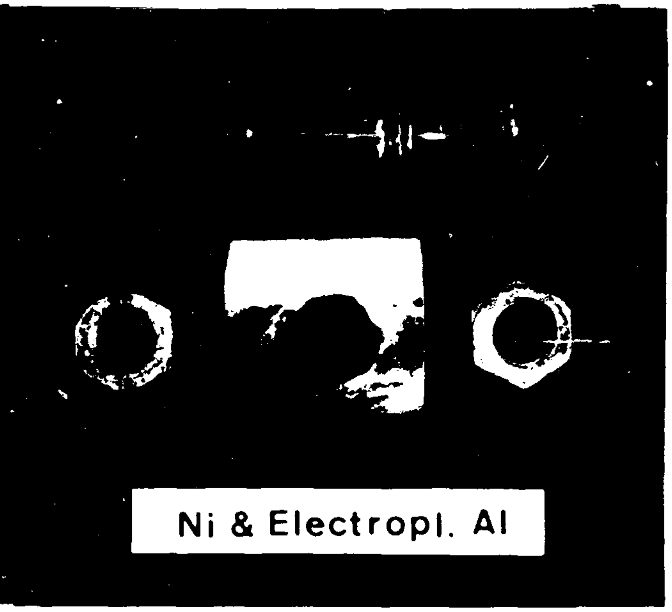


Photo 32.

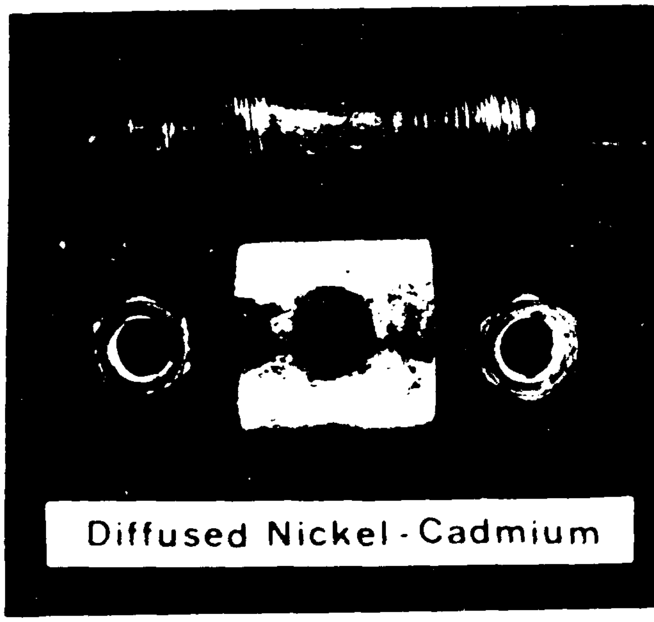


Photo 33.

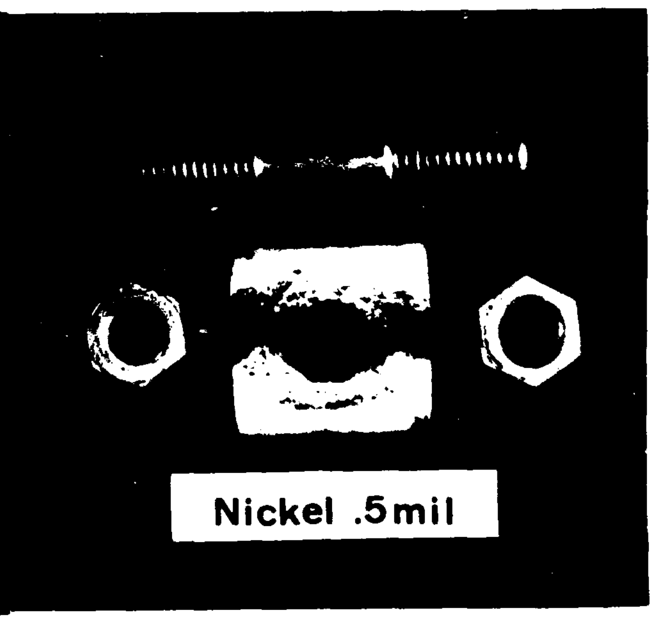


Photo 34.

High Temperature Screening Test Results - 2nd run 10 Oxidation-Corrosion Cycles - Metco 120 System used on cylinders.

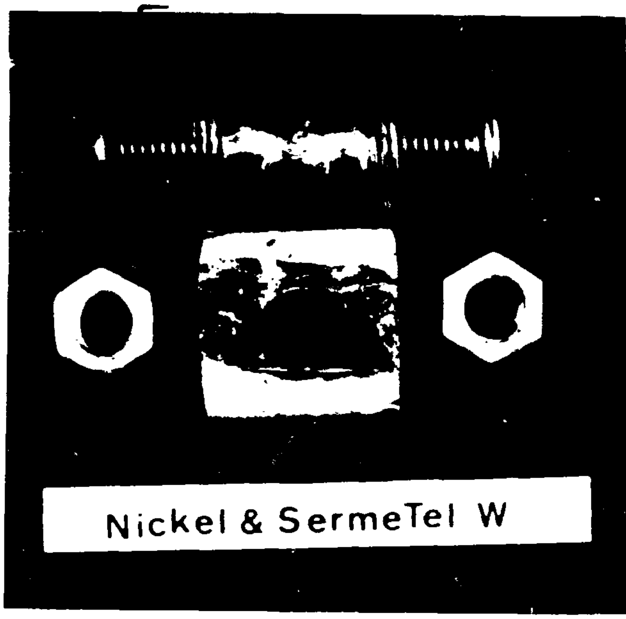


Photo 35.

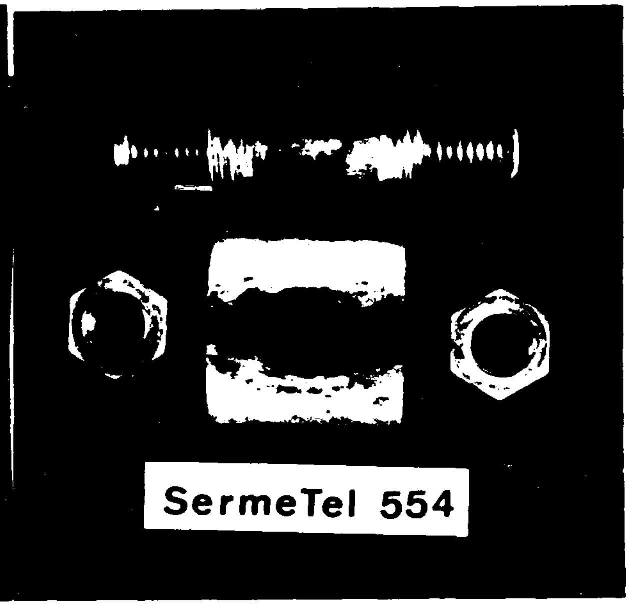


Photo 36.

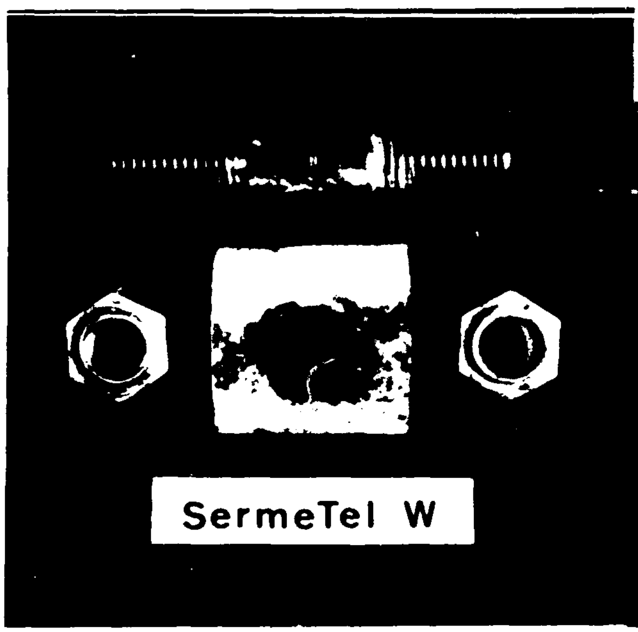


Photo 37.

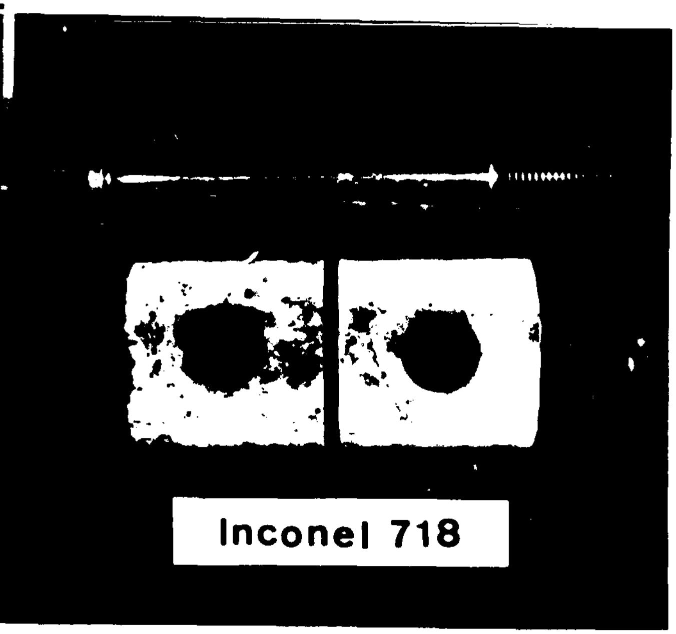


Photo 38.

High Temperature Screening Test Results - 2nd run 10 Oxidation-Corrosion Cycles - Metco 120 used on cylinders.

High temperature long term exposure

Photo 39. 9 month exposure at Ocean City produced rusting of steel block coated with TTP28 paint system. See Table XXV.

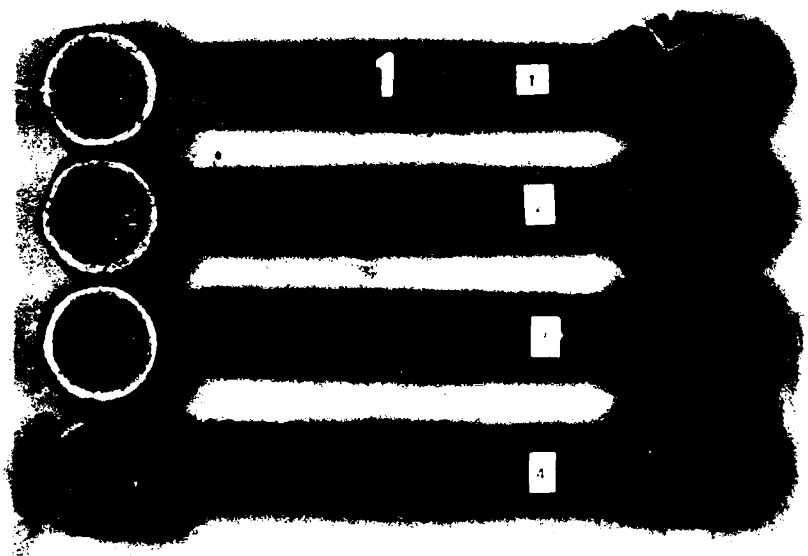


Photo 40. All bare alloy studs and nuts were severely rusted after 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

Photo 41. 9 month exposure at Ocean City produced limited galvanic corrosion around holes. See Table XXV.

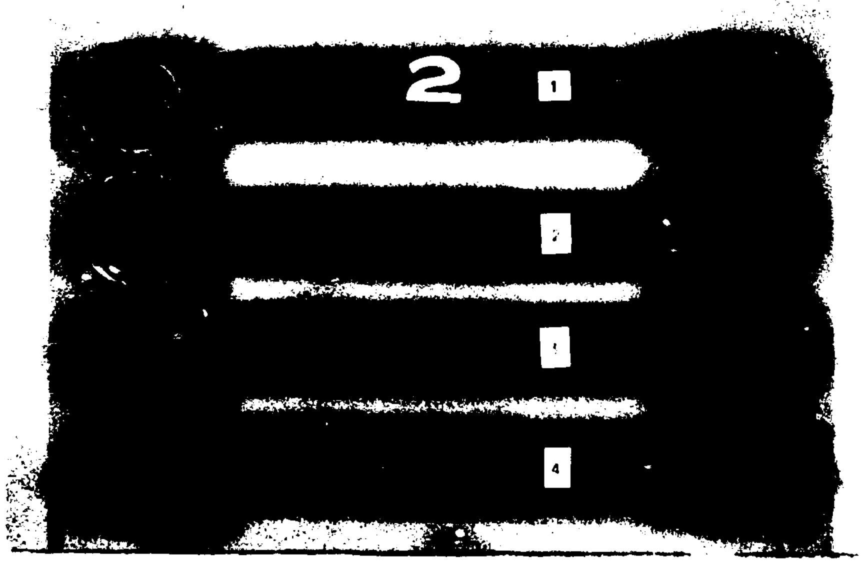


Photo 42. 0.4 mil nickel plated studs and nuts have very small amount of rust after the 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

Photo 43. 9 month exposure at Ocean City produced galvanic corrosion of coating system around hole. See Table XXV.

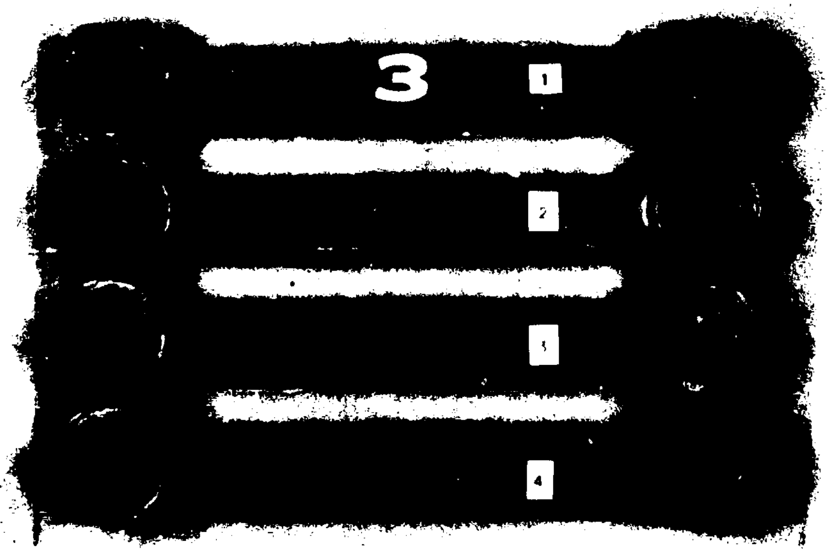


Photo 44. 0.7 mil nickel plated studs and nuts are virtually rust-free after the 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

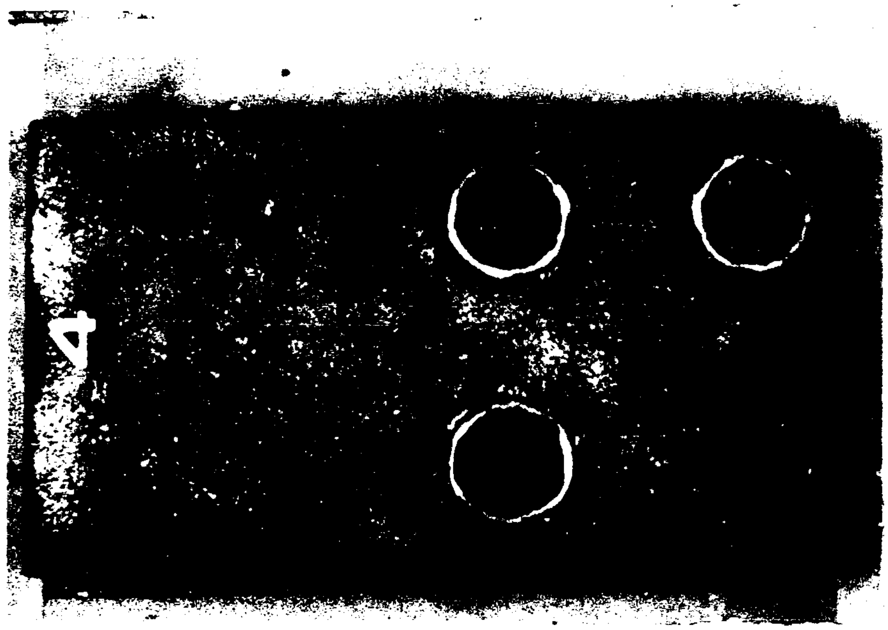


Photo 45. 9 month exposure at Ocean City produced limited Galvanic corrosion around holes. See Table XXV.

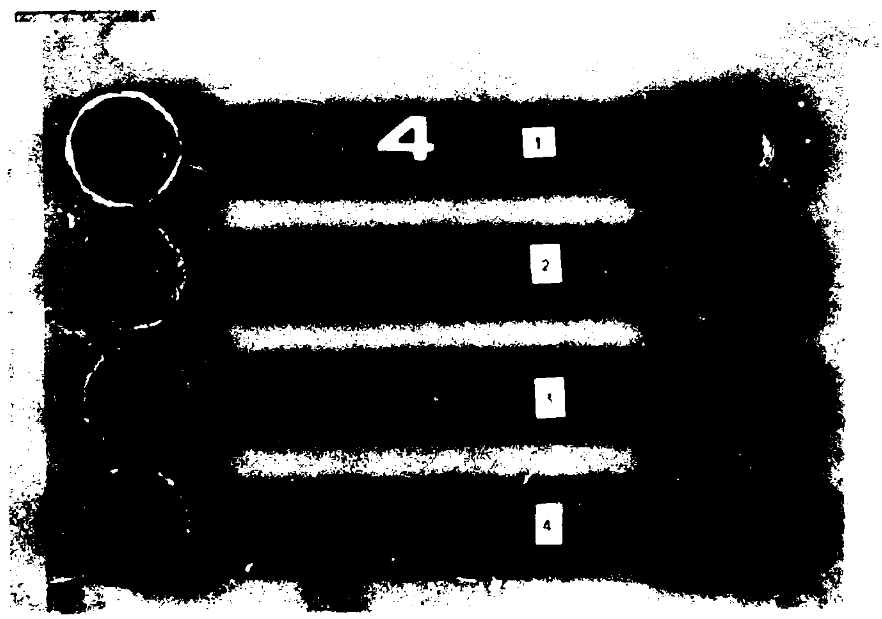


Photo 46. Diffused Ni-Cd coating on studs and nuts allowed slight rusting after the 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

Photo 47. 9 month exposure at Ocean City produced severe loss of sacrificial aluminim coating on steel block. See Table XXV.

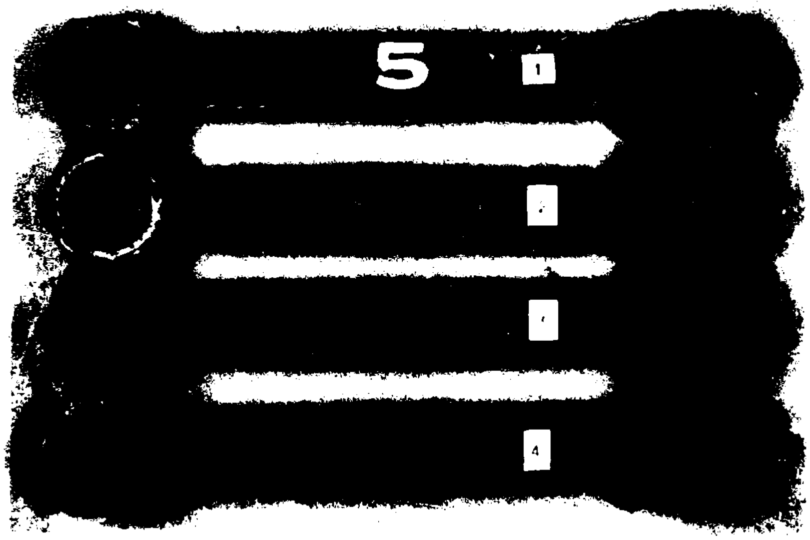


Photo 48. 0.4 mil electroless nickel plating on sutds and nuts allowed severe rusting after the 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

Photo 49. 9 month exposure at Ocean City produced little galvanic corrosion of coating system. See Table XXV.

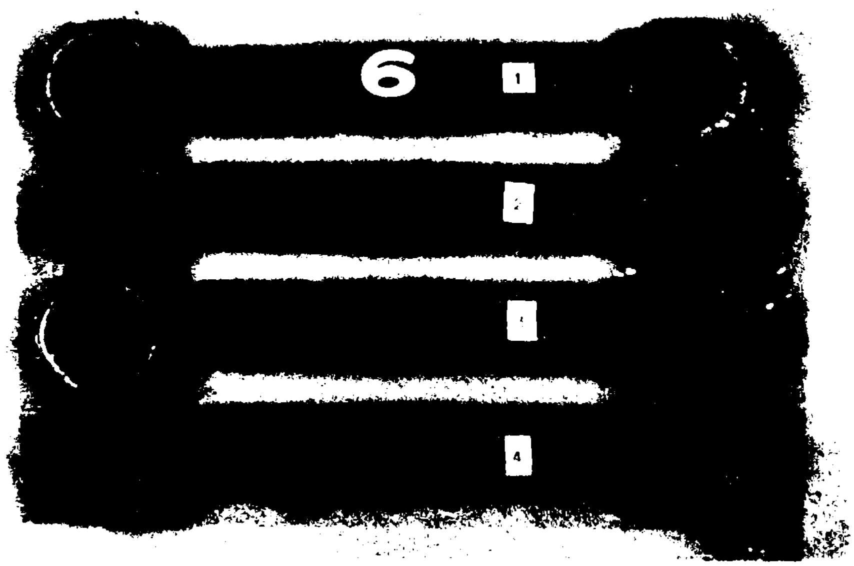


Photo 50. 0.7 mil electroless nickel plating on studs and nuts allowed rusting after the 9 months exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

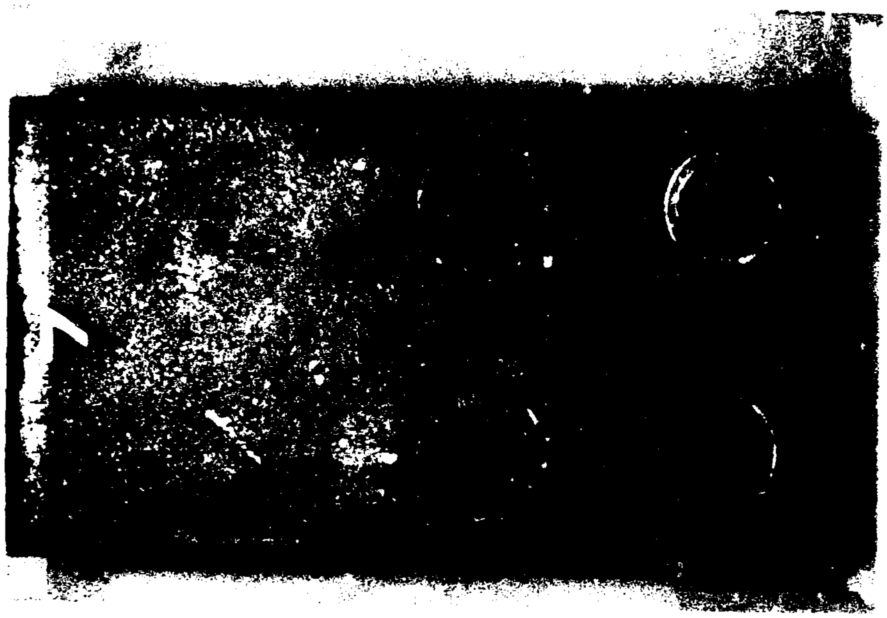


Photo 51. 9 month exposure at Ocean City produced little galvanic corrosion of coating system. See Table XXV.

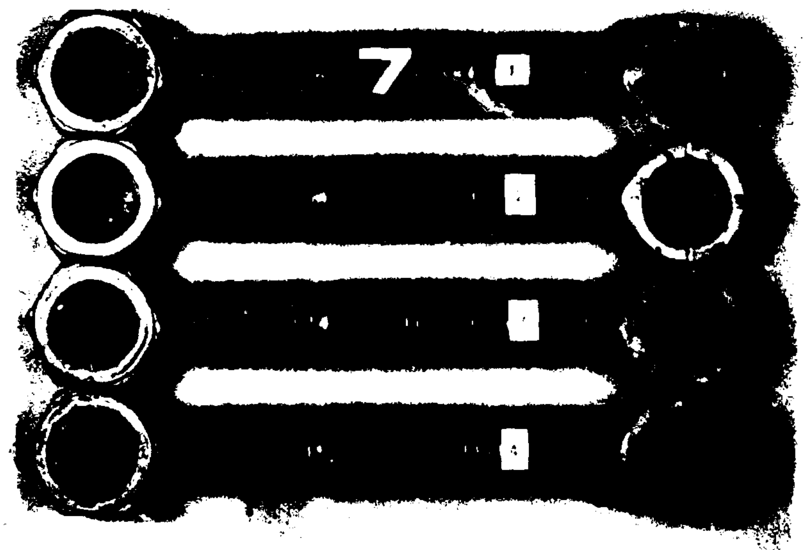


Photo 52. Electroplated nickel + SermeTel W coating system on studs and nuts allowed some rusting after the 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

Photo 53. 9 month exposure at Ocean City produced little galvanic corrosion of coating system. See Table XXV.

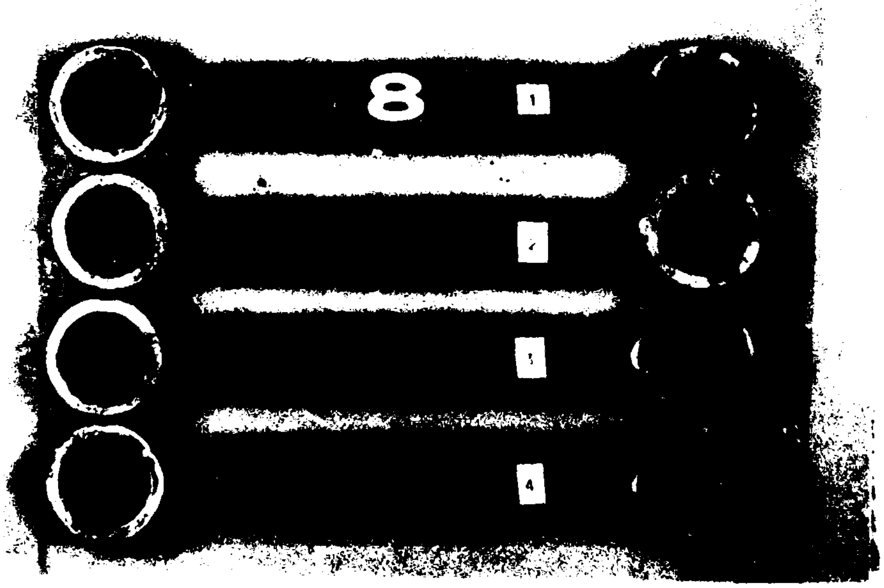


Photo 54. SermeTel W with a low temperature cure on studs and nuts allowed rusting to occur after 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

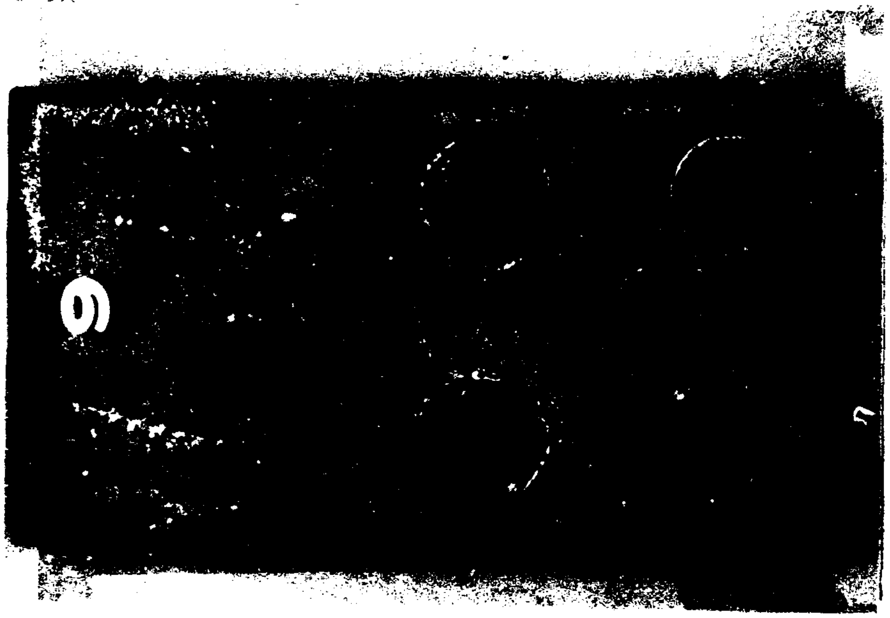


Photo 55. 9 month exposure at Ocean City produced little galvanic corrosion of coating system. See Table XXV.

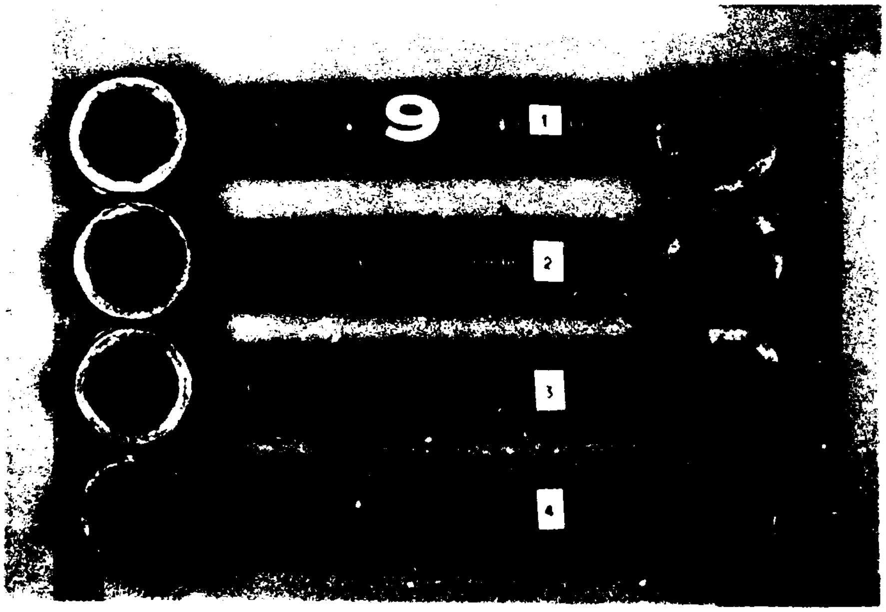


Photo 56. SermeTel W with a high temperature cure on studs and nuts allowed rusting to occur after 9 month exposure at Ocean City. See Table XXV.

High Temperature Long Term Exposure

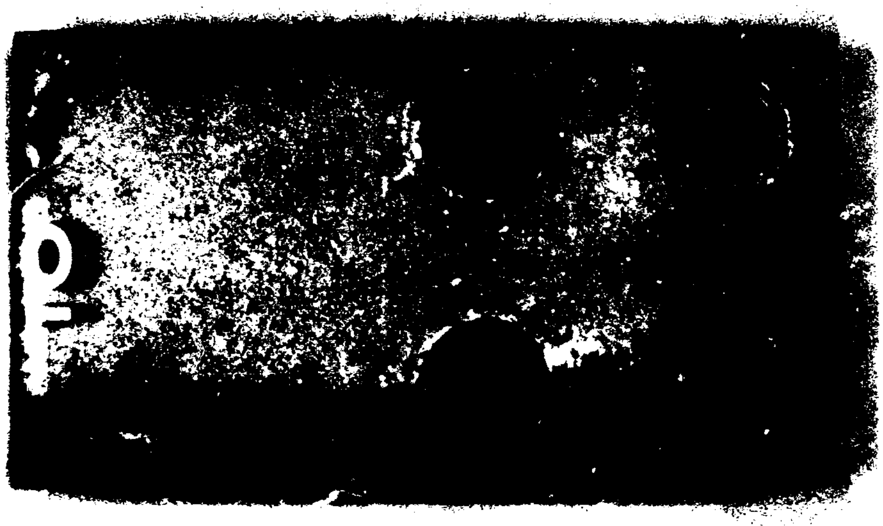


Photo 57. 9 month exposure at Ocean City produced depletion of sacrificial coating system around holes. See Table XXV.

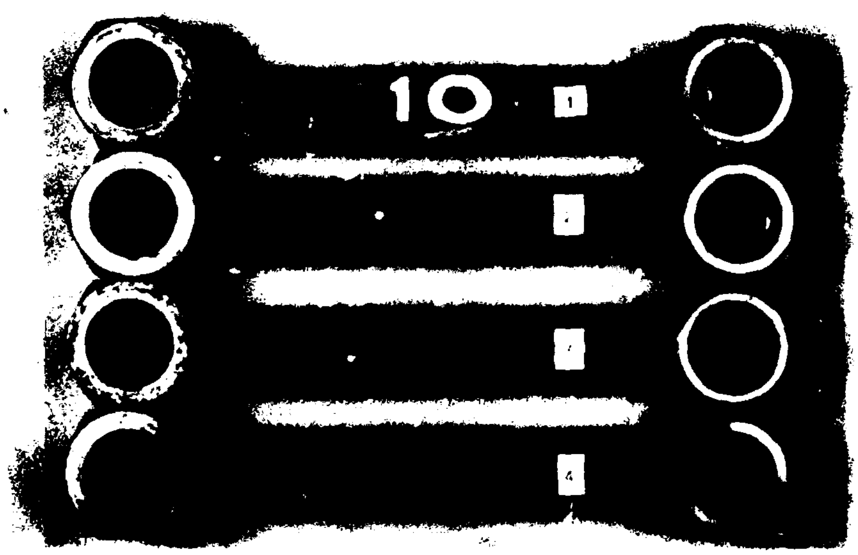


Photo 58. Inco 718 studs and nuts show no corrosion after a 9 month exposure at Ocean City. See Table XXV.

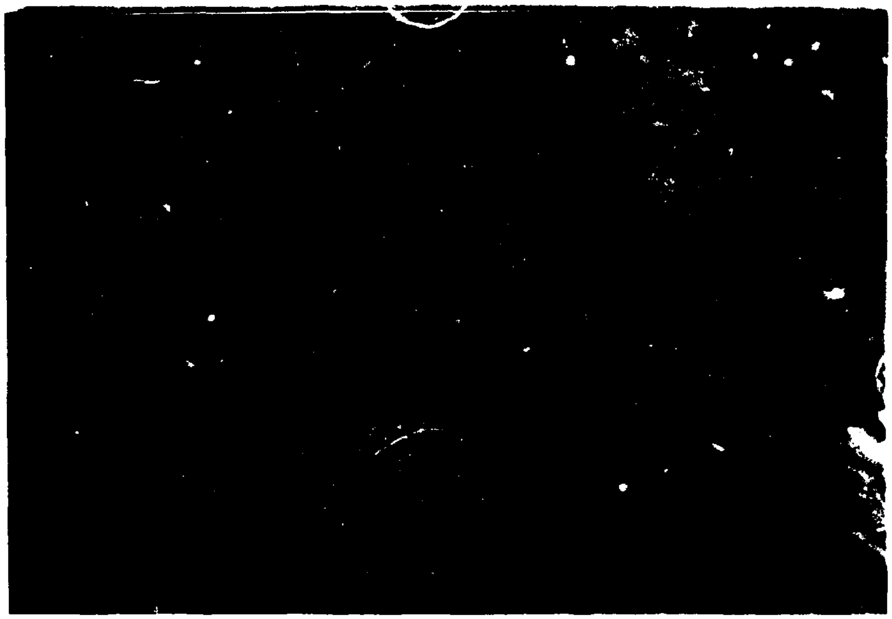


Photo 59 Bare studs and nuts after 6 months on the U.S.S. Saratoga exposure rack.

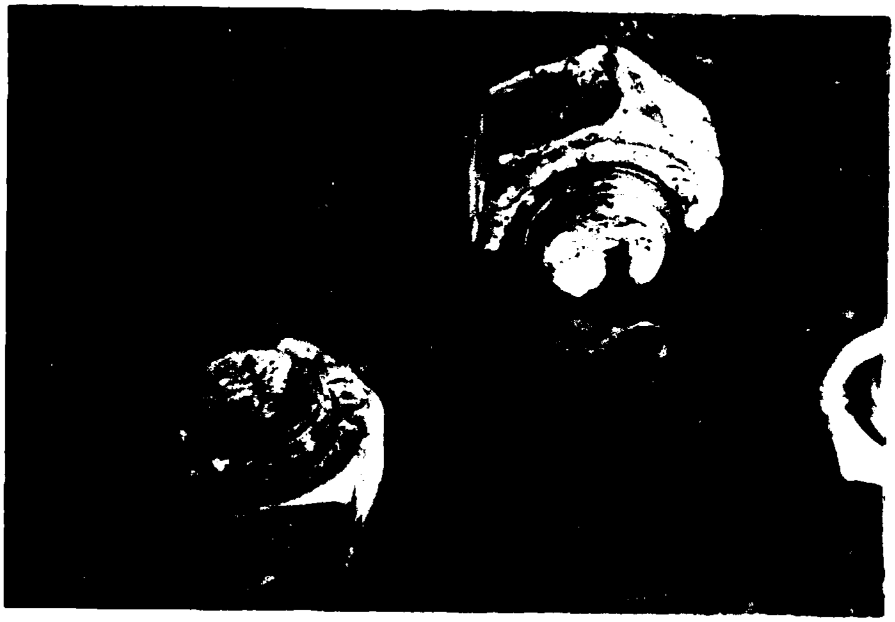


Photo 60 Diffused Ni-Cd coated studs and nuts after 6 months on the U.S.S. Saratoga exposure rack.

Photo [illegible]1. Studs and nuts coated with 0.7 mil electropl[illegible]
after 6 months on the U.S.S. Saratoga exposure rack.

Photo 62. Studs and nuts coated with 0.4 mil electroless nickel
after 6 months on the U.S.S. Saratoga exposure rack.

Photo 63. Studs and nuts coated with 0.4 mil electroplated nickel after 6 months on the U.S.S. Saratoga exposure rack.

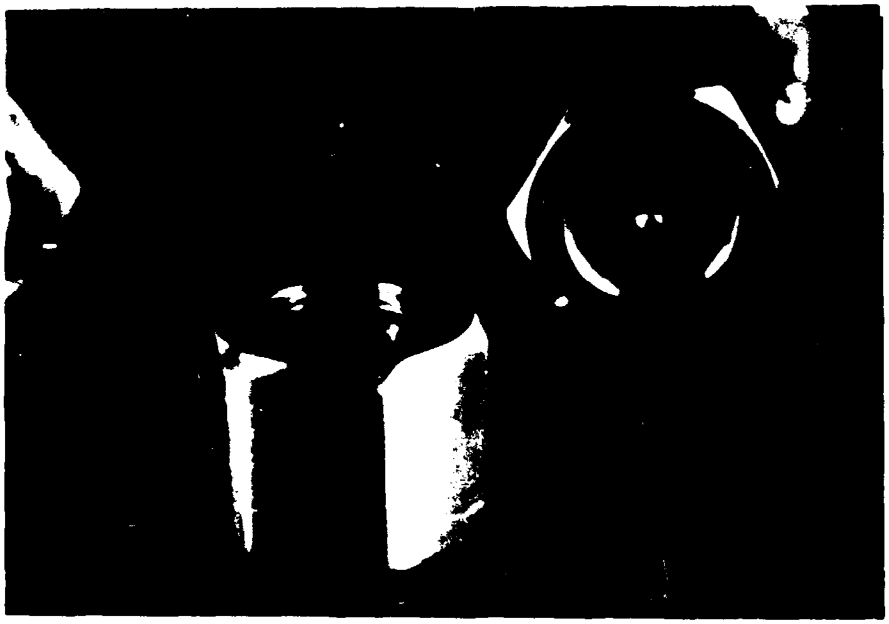


Photo 64. Inconel 718 stud and waspaloy nut after 6 months on the U.S.S. Saratoga exposure rack.

APPENDIX A

The following symbols are used and defined:

Symbol	Definition
A_B	Bolt area
A_j	Area of joint material
d	Bolt diameter
D_1	Flange inner diameter
D_2	Flange outer diameter
E_B^R	Modulus of elasticity of bolts at room temperature
E_B^T	Modulus of elasticity of bolts at 650°F
E_j^R	Modulus of elasticity of joint material at room temperature
E_j^T	Modulus of elasticity of joint material at 650°F
F_B	Bolt force
F_B^T	Bolt force at 650°F
F_j^T	Joint force at 650°F
F_T	Total joint preload due to all bolts at room temperature
Δl	Total change in length of bolt and joint due to temp. change
l_B	Bolt length
Δl_B^R	Bolt length change at room temperature
Δl_B^T	Bolt length change due to temperature change
l_j	Joint thickness
Δl_j^R	Joint compression at room temperature
Δl_j^T	Joint thickness change due to temperature change
Δl_T	Total change in length of bolt and joint at temperature, due to remaining preload
Δl_T^T	Total change in length of bolt and joint at 650°F
n	Total number of bolts in joint
ΔT	Change in temperature

α_B	Linear coefficient of expansion of bolt between room temperature and 650°F
α_j	Linear coefficient of expansion of joint material between room temperature and 650°F
ϵ_B	Bolt strain, inches/inch
ϵ_j	Joint strain, inches/inch
σ_B^R	Stress in bolt at room temperature
σ_B^T	Stress in bolt at 650°F
σ_j	Stress in flange (compressive)
σ_j^T	Stress in joint at 650°F

DEVELOPMENT OF EQUATIONS

At room temperature the joint area, A_j =

$$A_j = \frac{\pi}{4} (D_2^2 - D_1^2) - n (\frac{\pi}{4} d^2)$$

$$A_j = \frac{\pi}{4} (D_2^2 - D_1^2 - nd^2)$$

The flange stress $\sigma_j = \frac{F_T}{A_j}$ where $\epsilon_j^R = \frac{\sigma_j}{E_j^R} = \frac{\Delta l_j}{l_j}$

Therefore, $\Delta l_j = \epsilon_j^R \, l_j$

Therefore, $\sigma_j = \frac{4 \; F_T}{\pi (D_2^2 - D_1^2 - nd^2)}$

Therefore, $\epsilon_j^R = \frac{4 \; F_T}{\pi (D_2^2 - D_1^2 - nd^2) \; E_j^R}$

Therefore, $\Delta l_j^R = \frac{4 \; F_T \; l_j}{\pi (D_2^2 - D_1^2 - nd^2) \; E_j^R}$

which is the joint compression at room temperature.

The bolt force, $F_B = \frac{F_T}{n}$ where the bolt area, $A_B = \frac{\pi}{4} d^2$

$$\sigma_B^R = \frac{F_B}{A_B} = \frac{4\ F_T}{n\pi d^2}$$

$$\epsilon_B = \frac{\sigma_B^R}{E_B^R} \quad \text{Where } \epsilon_B = \frac{\Delta l_B}{l_B}$$

Therefore, $\Delta l_B = \epsilon_B l_B$

Therefore, $\Delta l_B^R = \dfrac{4\ F_T\ l_B}{n\pi d^2\ E_B^R}$

which is the bolt length change at room temperature

$$\text{At } 650°\text{F}, \ \Delta l_B^T = l_B \alpha_B \Delta T$$

$$\Delta l_j^T = l_j \alpha_j \Delta T$$

$$\Delta l = \Delta l_B^T - \Delta l_j^T = (l_B \alpha_B - l_j \alpha_j)\Delta T$$

$$\Delta l_T = \Delta l_j^R + \Delta l_B^R - \Delta l$$

$$\Delta l_T = \frac{4\ F_T\ l_j}{\pi (D_2^2 - D_1^2 - nd^2)\ E_j^R} + \frac{4\ F_T\ l_B}{n\pi d^2\ E_B^R} = (l_B \alpha_B - l_j \alpha_j)\Delta T$$

or

$$\Delta l_T = \frac{F_T\ l_j}{(A_j - nA_B)\ E_j^R} + \frac{F_T\ l_B}{n\ A_B\ E_B^R} - (l_B \alpha_B - l_j \alpha_j)\Delta T \qquad (1)$$

The remaining bolt load at temperature is determined as follows:

Since $F_j^T = \sigma_j^T A_j$ and $F_B^T = \sigma_B^T A_B$, and $F_j^T = n\ F_B^T$,

Then $\sigma_j^T = E_j^T \dfrac{\Delta l_j^T}{l_j}$ and $\sigma_B^T = E_B^T \dfrac{\Delta l_B^T}{l_B}$

But $\sigma_j^T A_j = n\sigma_B^T A_B$ and $\Delta 1_j^T + \Delta 1_B^T = \Delta 1_T^T$

Therefore $\sigma_j^T = \dfrac{n\sigma_B^T A_B}{A_j} = E_j^T \dfrac{\Delta 1_j^T}{1_j}$

$$\sigma_B^T = \frac{E_j^T \Delta 1_j^T A_j}{n\ A_B\ 1_j}$$

$$\sigma_B^T = E_B^T \frac{\Delta 1_B^T}{1_B}$$

Therefore $\dfrac{E_j^T\ \Delta\ 1_j^T\ A_j}{n\ A_B\ 1_j} = \dfrac{E_B^T \Delta 1_B^T}{1_B}$

or $\Delta 1_B^T = \dfrac{E_j^T\ 1_B\ \ A_j \Delta 1_j^T}{E_B^T\ 1_j\ \ A_B\ \ n}$

Therefore $\Delta 1_B^T = \dfrac{1}{n}\ \dfrac{E_j^T\ 1_B\ A_j}{E_B^T\ 1_j\ A_B}\ (\Delta 1_T^T - \Delta 1_B^T)$

If $K = \dfrac{1}{n}\ \dfrac{E_j\ \cdot 1_B\ A_j}{E_B^T\ \ 1_j\ A_B}$ (2)

Then $\Delta 1_B^T = K \Delta 1_T^T - K\Delta 1_B^T$

or $\Delta 1_B^T\ (1 + K) = K \Delta 1_T^T$

Therefore $\Delta 1_B^T = \dfrac{K}{(1 + K)} \Delta 1_T^T$ (3)

and $F_B^T = \sigma_B^T\ A_B$ or $E_B^T\ A_B\ \dfrac{\Delta 1_B^T}{1_B}$ (4)

The solution of equations 1 through 4 will yield the remaining bolt preload at temperature.

The Corrosion Control of Fastening Systems for Aircraft Carrier Steam Catapults

NAEC-ENG -
NAEC CONTRACT NO.
N00156-73-C-0852

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